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Initial Evaluation of Alternatives for Development of Sediment Related Criteria for Toxic Contaminants in Marine Waters (Puget Sound). Phase 2. Development and Testing of the Sediment-Water Equilibrium Partitioning Approach

JRB Associates, Inc., Bellevue, WA

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With the increased use of our nation's coastal and inland waters, regulatory agencies are frequently confronted with difficult decisions in resolving conflicts between alternative uses of these waters, while at the same time striving to protect overall environmental quality. A significant number of management decisions facing these agencies concern the definition of permissible levels of contaminants in marine sediments. For example, in Commencement Bay the Washington Department of Ecology and EPA are attempting to identify those areas in which sediment contamination poses the greatest environmental threat, with the ultimate intent of -nitiating remedial action in these areas. At the Four Mile Rock dredge disposal site, regulatory agencies are confronted with an immediate need to establish a permissible level of contamination for sediments which are to be disposed of at the site. In Commencement Bay, at Four Mile Rock, and at countless other areas throughout the country, sediment related criteria which define environmentally safe levels of contaminants in sediments would be invaluable tools in environmental management decisions. However, given the current state of our technical knowledge, regulatory agencies have been forced to adopt short-term, interim decision criteria until scientifically-sound and legally defensible sediment criteria can ultimately be established.

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INITIAL EVALUATION OF ALTERNATIVES FOR DEVELOPMENT OF SEDIMENT RELATED CRITERIA FOR TOXIC CONTAMINANTS IN MARINE WATERS (PUGET SOUND)

PHASE II: DEVELOPMENT AND TESTING OF THE SEDIMENT-WATER EQUILIBRIUM PARTITIONING APPROACH

FINAL REPORT

April 20, 1984

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1.0 EXECUTIVE SUMMARY

With the increased use of our nation's coastal and inland waters, regulatory agencies are frequently confronted with difficult decisions in resolving conflicts between alternate uses of these waters, while at the same time striving to protect overall environmental quality. A significant number of management decisions facing these agencies concern the definition of permissible levels of contaminants in marine sediments. For example, in Commencement Bay the Washington Department of Ecology and EPA are attempting to identify those areas in which sediment contamination poses the greatest environmental threat, with the ultimate intent of initiating remedial action in these areas. At the Four Mile Rock dredge disposal site, regulatory agencies are confronted with an immediate need to establish a permissible level of contamination for sediments which are to be disposed of at the site. In Commencement Bay, at Four Mile Rock, and at countless other areas throughout the country, sediment-related criteria which define environmentally safe levels of contaminants in sediments would be invaluable tools in environmental management decisions. However, given the current state of our technical knowledge, regulatory agencies have been forced to adopt short-term, interim decision criteria until scientifically-sound and legally defensible sediment criteria can ultimately be established.

There are three general approaches currently being pursued to establish sediment-related criteria:

- Background level approach - criteria are established at some permissible level of enrichment above background levels in a reference area.
- Burden-effect relationships - observations of adverse biological impacts are related to contaminant concentrations in order to establish a "safe" level of contamination.
- Equilibrium partitioning approach.

In an effort to develop the equilibrium partitioning approach, JRB Associates was contracted to develop the theoretical framework of the approach. Using this framework, JRB then developed tentative criteria for trace metals and synthetic organics and tested the proposed criteria against measurements of contaminants in the sediments of Puget Sound.

The results of this study suggest that the equilibrium partitioning approach is a method that holds much promise for establishing criteria for marine sediments. The approach provides a relatively simple mechanism whereby the large toxicological data base incorporated in the EPA water quality criteria can be adapted to determine permissible contaminant concentrations in marine sediments which should insure protection of benthic marine organisms. The basic tenet of the equilibrium partitioning approach is that the concentration of each contaminant in sediment should be at or below a level which insures that its concentration in interstitial water does not exceed the EPA water quality criterion.

The key to this approach is the determination of the sediment-water partition coefficient for each compound of interest. This coefficient was determined empirically for trace metals based on measurements of trace metal concentrations in the interstitial water and bulk sediments from a wide variety of substrates. The sediment-water partition coefficients for synthetic organics were estimated from octanol-water partition coefficients. Since the partitioning of a contaminant between sediment and water is strongly dependent upon the organic carbon content of the sediment, the partition coefficient is normalized to organic content.

Sediment criteria were established for six trace metals and 47 synthetic organic compounds of concern in Puget Sound by use of the equlibrium partitioning approach. The derived criteria were tested against existing data on sediment contaminant concentrations in a variety of areas in Puget Sound including Elliott Bay, Commencement Bay, Sinclair Inlet, Budd Inlet, Case Inlet, Port Madison and the West Point area. In most cases the proposed criteria were exceeded only in areas which historically have received high inputs of contaminants from point and nonpoint sources. Among the trace metals, chronic sediment criteria were exceeded most frequently for Hg, Pb, Cu and As in Elliott Bay and Commencement Bay. Among the synthetic organics, only PCBs and DDT consistently exceeded the proposed sediment criteria, primarily in the urban embayments noted above. The polynuclear aromatic hydrocarbons were generally well below criteria except for a few isolated sites in the West Point area. Both numerical and graphical procedures are presented to relate the frequency and magnitude of criteria violations to specific sites.

During development of the equilibrium partitioning approach, a number of shortcomings in our current state of knowlege on pollutant interactions between sediment, water and biota have been identified. The most significant of these include:

- inability to consider synergistic or antagonistic interactions among contaminants;
- the influence of environmental variables (e.g., organic carbon, pH) on the chemical behavior of contaminants is poorly understood; and
- our inability to differentiate the bioavailable fraction of a contaminant from the total sediment burden of the contaminant.

Until some of the issues identified above are resolved, the sediment criteria proposed in this report are not intended for adoption by regulatory agencies. It is important to recognize that while the numerical values suggested in this report as permissible levels of contaminants in marine sediments are, for simplicity sake, referred to as "criteria", they are not appropriate for immediate use in any regulatory, control or enforcement applications. However, as a first step in a long process, the approach presented herein appears very promising for the eventual adoption of sediment criteria for regulatory application.

The approach developed in this report is noteworthy in that it is capable of providing numerical criteria for a wide diversity of contaminants in marine sediments. This in itself is an elusive goal which has been unachieveable in many past efforts. However it is the approach which has been developed, rather than the criteria per se, which represents the most signficiant contribution of this work. The criteria proposed in this report are presented with the expectation that they will be refined through an iterative process involving input from both the scientific community and environmental management agencies. With continued refinement, the criteria will find application on the short-term basis as guidelines in assisting environmental managers in assessment of the extent of contamination of marine sediments. On a long-term basis, the criteria may ultimately be refined to the point where they find broad regulatory application.

2.0 INTRODUCTION

2.1 RATIONALE AND OBJECTIVES

The Environmental Protection Agency has focused historically on the development of water quality criteria which are supported by a broad base of toxicological studies. Use of these criteria provides some degree of assurance that contaminant concentrations will be within acceptable limits for the protection of aquatic life and human health. However, there is disturbing evidence of environmental degradation in many of the heavily urbanized areas of Puget Sound even though monitoring data does not show that water quality criteria are exceeded in the water column. The majority of adverse biological impacts recently observed are not among organisms living in the water column but those that live in or on the sediments. Macrobenthic communities in the vicinity of point source discharges have demonstrated significant changes in species composition and abundance (Armstrong, et al., 1978; Malins et al., 1982; Comiskey et al., 1983). Sediments from urbanized areas have been shown to induce mortality in sensitive benthic species (Swartz et al., 1982), and demersal fishes from heavily polluted areas have been shown to have a higher incidence of histopathological abnormalities than those from reference areas (Malins et al., 1980; 1982). These observations raise serious questions as to whether existing water quality criteria alone are adequate to protect the environmental resources of Puget Sound.

It is becoming increasingly evident that some sort of sediment criteria are needed to supplement existing water quality criteria in judging the significance of contaminant concentrations and to provide a basis for remedial action. There are a number of reasons why sediment criteria deserve consideration:

- Most toxic compounds are highly insoluble so the majority of the contaminant is not dissolved in the water but is associated with the organic matrix on sediment particles. For example, sediments in Elliott Bay contain 60,000 times more PCBs than overlying water (Pavlou and Dexter, 1979).

- Sediments serve to integrate contaminant concentrations over time, eliminating the high degree of temporal variability which plagues sampling of toxicants in the water column.

- Sediments serve as a sink for most toxic materials, thus a long-term low level discharge of a contaminant may result in a dangerous build up in the sediment even though water quality criteria are not violated at any given time.

- Sediments can serve as a reservoir (source) of contaminants which could be reintroduced to unpolluted overlying water.

- A large number of organisms, including many of commercial importance, spend most of their lives in or on the sediments. For these species, the contaminant level in the sediments may be of greater concern than that in the overlying water and may be the controlling factor with regards to bioaccumulation potential.

In response to the need for sediment-related criteria, the Environmental Protection Agency initiated an effort to identify and evaluate alternative approaches to the establishment of sediment criteria. The current state of knowledge regarding sediment criteria was updated and summarized in the Phase I report (Pavlou and Weston, 1983) and a number of approaches to the establishment of criteria were identified. Three approaches appeared to be of immediate utility in developing sediment criteria for Puget Sound:

- Background level approach - the concentration of contaminants in the sediments of relatively unpolluted reference areas is determined and the criteria are then established at some permissible level of enrichment above background levels;

- Burden-effect relationships - observations of adverse biological impacts (alterations in benthic community structures, lethal or sublethal effects observed in bioassays, incidence of pathological disorders) are correlated with contaminant concentration in order to determine those concentrations at which no impacts are evident;

- Equilibrium partitioning approach - the sediment criterion is established at a level which will insure that the EPA water quality criterion is not violated in the interstitial water.

The development of sediment criteria by the background level approach and burden-effect relationships is currently underway in connection with other work within Region X. JRB was requested to develop the equilibrium partitioning approach and to examine the suitability of the approach for the establishment of sediment criteria for Puget Sound. The approach is simple, is immediately adaptable to the chemical contaminants measured in Puget Sound, is based primarily on existing data and provides "first cut" numerical criteria values.

2.2 OBJECTIVES

The specific objectives of the Phase II activities in this study were to:

1. Present the theoretical basis of the equilibrium partitioning approach and the derivation of sediment-water partition coefficients. Discuss their application in the marine environment and their dependence on environmental variables.

2. Establish preliminary numerical criteria for selected compounds measured in Puget Sound and estimate the uncertainty in these numerical values.

3. Discuss the assumptions and limitations of the approach and how they may influence the application of the derived criteria.

4. Test the utility of the derived criteria in Puget Sound with representative data sets from contaminated embayments.

5. Identify future research/data needs which may serve to improve the utility of the equilibrium partitioning approach.

2.3 SUMMARY OF APPROACH

Sediment criteria were derived for six priority metals and 47 individual priority organic compounds. These contaminants have been measured historically in the sediments of Puget Sound and have shown elevated concentrations within certain subregions and embayments of the Main Basin.

In this study, a sediment criterion was defined as the concentration of a contaminant in sediment which insures that its concentration in interstitial water does not exceed the established EPA water quality criterion, and therefore a designated water use, such as integrity of indigenous biota, could be attained. The sediment criterion was expressed as the product of the compound-specific sediment-water partition coefficient and its water quality criterion.

For trace metals, the partition coefficients were computed from the literature as an arithmetic mean with an associcated standard deviation. For synthetic organic compounds the partition coefficients were computed from existing relationships of experimentally derived sediment-water partition coefficients with octanol-water partitioning ratios. Seven regression equations published in the literature, for a variety of chemical classes, were considered for their applicability to the compounds tested in this study. The optimum equation selected was one derived for 19 priority organic chemicals.

Sediment criteria for each of 53 priority pollutants were derived to correspond to both the acute and chronic values established for water, when available. The applicability of these derived criteria in Puget Sound was tested with two independent data sets. The contaminant concentrations measured in the sediments of various subregions in Puget Sound were compared with the criteria values. Violations were then estimated as excess factors from the derived acute and/or chronic criterion value. A comparison of the frequency of criteria violations values computed among a number of subregions and embayments allowed for a preliminary assessment of the severity of contamination.

The discussion presented in the ensuing sections of this report is a detailed description of the above approach and results obtained.

3.0 TECHNICAL DEVELOPMENT

3.1 BASIC DEFINITIONS

A brief discussion of the concept of equilibrium partitioning was presented in the Phase I report, Section 2.4. As applied to the sediment-water interface, contaminant transport between the solid and aqueous phase occurs via a rapid molecular exchange. This exchange is continuous and therefore maintains the system at chemical equilibrium. The instantaneous concentration of the contaminant in either of the two components can be expressed as a function of its concentration in the other component and an equilibrium constant specific to that contaminant. These chemical specific constants are commonly referred to as partition coefficients and are expressed mathematically as:

$$K_D = \frac{C_S^X}{C_W^X} \qquad (1)$$

where K_D is the partition coefficient and C_S^X and C_W^X are the concentrations of contaminant x in the sediment (s) and surrounding water (w), respectively. Contaminant concentrations are expressed as mass of x/dry mass of sediment and mass of x/mass of water.

A schematic representation of the aqueous-solid components in a marine environment where this mechanism is operable is shown in Figure 1. Partitioning of a contaminant occurs in both the water column and the sediments. In the former case, the exchange is between suspended particulate matter (SPM) and ambient water while in the latter case it is between sediment particles and the interstitial water. In applying the equilibrium partitioning approach to sediments, the zone of interest for developing sediment criteria is the bioturbation layer where most of the biological activity occurs. Sediment criteria using the equilibrium partitioning approach were derived using equation (1) as follows:

- The partition coefficient, K_D, was adjusted to account for the dependence on organic carbon. The modified partition coefficient is defined as:

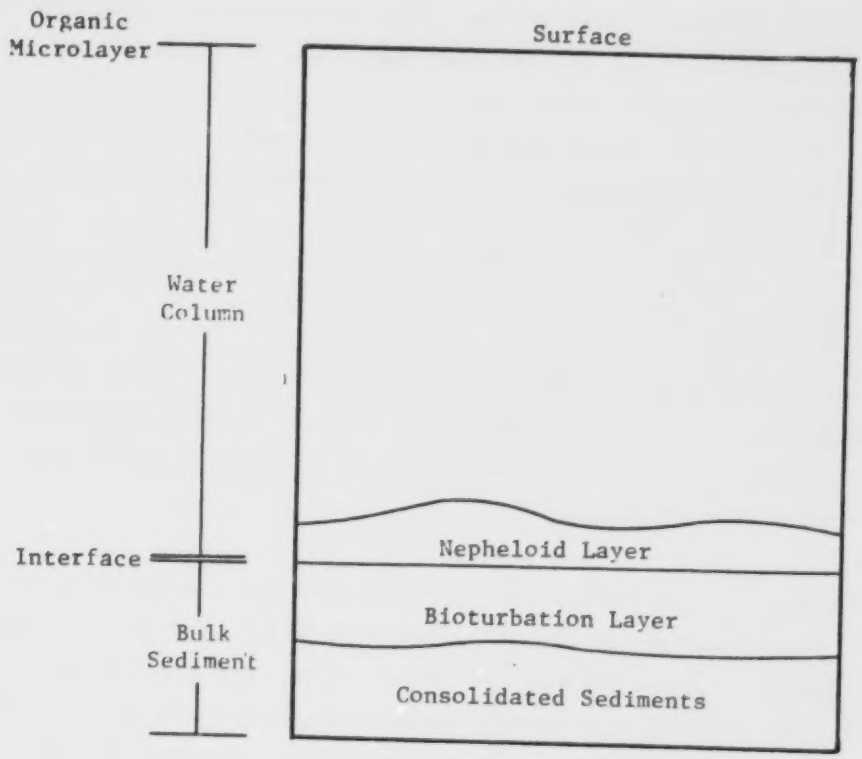

Figure 1

SCHEMATIC REPRESENTATION OF AQUEOUS-SOLID
COMPONENTS IN THE MARINE ENVIRONMENT

$$K_{OC} = \frac{C^X_{S/OC}}{C^X_{IW}} \qquad (2)$$

where K_{OC} is the organic carbon normalized partition coefficient and $C^X_{X/OC}$ is now the concentration of contaminant x in the sediment expressed in units of mass of x/mass of organic carbon. The term C^X_{IW} refers specifically to the concentration of x in interstitial water; the units remain the same as defined in equation (1). Equation (2) can also be expressed as:

$$K_{OC} = \frac{C^X_S}{C^X_{IW}} \times \frac{1}{TOC} = K_D \times \frac{1}{TOC} \qquad (3)$$

where TOC refers to the total organic carbon content in sediment expressed as the fractional mass on a dry weight basis (e.g., 3% organic carbon equals 0.03 g organic carbon per 1 g of sediment dry weight). This adjustment was made to eliminate the variability of K_D on organic carbon. The dependence of K_D on organic carbon has been well documented in the literature. For example, K_D values for nitropyrin were shown to vary about 140-fold in different sediment samples but when expressed on an organic carbon basis (K_{OC}) the variation was reduced to only threefold (Kenaga and Goring, 1980). A similar dependence on sediment-water partitioning on organic carbon content is evident for benzo(a)pyrene as depicted in Figure 2. K_D values for each of three sediment types were found to vary considerably (3.5×10^4 to 15×10^4) though when adjusted to organic carbon content the variability was minimal (3.0×10^6 to 3.8×10^6).

- The sediment criterion is defined as the concentration of contaminant x in the sediment which insures that its concentration in the interstitial water does not exceed the established EPA water quality criterion. Modifying equation (2) by setting C^X_{IW} as the water quality criterion, $C^X_{W/CR}$, then the corresponding sediment criterion for contaminant x, $C^X_{S/CR/OC}$, can be expressed as:

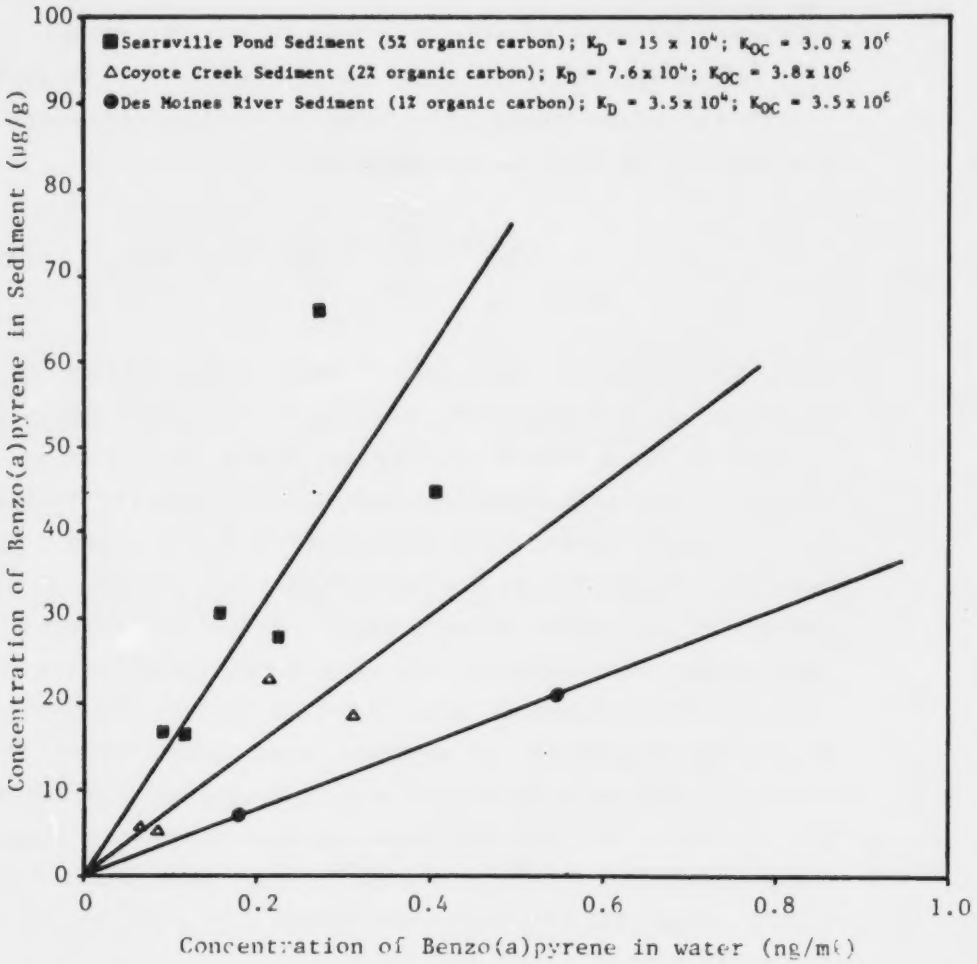

Figure 2

SORPTION ISOTHERMS OF BENZO(A)PYRENE
(From Smith et al., 1978)

$$C^X_{S/CR/OC} = K_{OC}\, C^X_{W/CR} \qquad (4)$$

- In order to apply the sediment criterion to a specific site, the criterion normalized to organic carbon, may be adjusted to the amount of organic carbon in the sediment of concern. This is expressed as:

$$C^X_{S/CR} = C^X_{S/CR/OC}\, TOC \qquad (5)$$

in which T_{OC} is again expressed as the fractional mass on a dry weight basis as in equation (3). The sediment criterion for a given organic carbon content, $C^X_{S/CR}$ can be compared directly to the measured contaminant concentration in the sediment of concern.

The procedures followed in deriving sediment criteria for specific priority pollutants measured in Puget Sound and in testing the application of these numerical values with existing data, are presented in detail in the following sections of the report.

3.2 DETERMINATION OF PARTITION COEFFICIENTS (K_{OC})

Partition coefficients were computed for six priority metals and 47 priority organic compounds which have been measured in Puget Sound sediments. The methods used are presented separately for the two categories of pollutants.

3.2.1 Trace Metals

The distribution of trace metals between interstitial water and sediment is a complex process which depends on a number of factors including chemical speciation, the reduction-oxidation (redox) potential at the solid-aqueous interface, the type of clay minerals present, the nature of the organic matter on both sedimentary particles and in interstitial water, pH, salinity, and particle size. The redox potential and pH, because of their effects on chemical speciation, are probably the most important factors in determining the sediment-water partitioning of trace metals (Jenne and Luoma, 1979). Though the dependence of partitioning on pH and redox conditions is certainly of major importance, the precise nature of this dependence is unpredictable and poorly understood.

The environmental variables and physical/chemical processes responsible for mediating the transport of trace metals in marine sediments are neither well understood nor adequately quantifiable to allow a theoretical computation of sediment-water partition coefficients. Therefore, these coefficients were derived empirically by using measurements of trace metal concentrations in the interstitial water and bulk sediments from a wide variety of substrate types. Empirical K_{OC} values were then calculated for each substrate type and a mean of the individual K_{OC} values was computed to determine a partition coefficient most representative of that particular trace metal.

Upon examination of the recent literature, the most comprehensive data was that of Brannon et al. (1980); the derivation of the K quantities presented in the present report rely solely on this data base. In the study of Brannon et. al, samples were taken from a wide variety of areas throughout the country, primarily from marine sediments but including a few freshwater sites as well. From each site, measurements were made of trace metal concentrations in the bulk sediment and in the interstitial water. K_D values calculated from this data are presented in Table 1. The K_D values were converted to K_{OC} values by dividing by the fractional mass of the sediment organic carbon concentrations.

As discussed in the previous section (Section 3.1) there is clear justification for normalizing the partitioning coefficient of synthetic organics to sediment organic content by use of K_{OC} rather than K_D but for trace metals the issue is more problematic and requires further examination. Of the six metals evaluated, a statistically significant relationship between K_D and organic content was evident for three metals (Cu, Cd, Pb) as shown in Table 2 and Figure 3. For these three metals it is clear that K_{OC} would be a better estimate of the sediment-water partitioning than would K_D. For the remaining three metals (Zn, As, Hg) the apparent independence of partitioning on sediment organic content is not taken as definitive evidence against the use of K_{OC}. It is very probable that the diversity of sites and variations in other environmental parameters among sites (e.g., redox potential) may have masked the relationship of K_D and organic carbon. It is noteworthy that even though normalization of mercury concentrations to organic carbon was not indicated as appropriate by this analysis, Lindberg and Harris (1974) found comparisons of mercury concentrations among sites to be more meaningful after the concentrations were first normalized to sediment organic content.

Table 1

EMPIRICAL SEDIMENT-WATER PARTITION COEFFICIENTS FOR TRACE METALS
(Values calculated from Brannon et al., 1980, as the ratio of total sediment metal concentration to the concentration of the metal in the interstitial water)[a]

		Cu		Zn		As		Cd		Pb		Hg	
Collection Site	Organic Carbon (%)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)	K_D ($\times 10^3$)	K_{OC} ($\times 10^5$)
Mobile Bay, AL	0.82	1.8	2.2	2.0	2.4	0.25	0.30	0.06	0.07	3.5	4.3	0.15	0.18
Mobile Bay, AL	2.74	16.9	6.2	2.7	1.0	0.31	0.11	0.11	0.04	1.9	0.7	0.04	0.01
Duwamish Waterway, WA	1.42	8.4	5.9	11.8	8.0	0.44	0.31	0.04	0.03	4.0	2.8	0.67	0.47
Duwamish Waterway, WA	2.84	131.4	46.3	2.7	1.0	0.36	0.13	1.23	0.43	36.3	12.8	0.47	0.17
Duwamish Waterway, WA	1.98	49.7	25.1	11.4	5.7	0.28	0.14	1.02	0.14	4.2	2.1	0.25	0.13
Branford Harbor, CT	4.26	184.9	43.4	4.5	1.1	0.44	0.10	1.32	0.31	16.4	3.8	0.08	0.02
Branford Harbor, CT	5.12	93.7	18.3	0.9	0.2	0.08	0.02	1.11	0.22	13.4	2.6	0.20	0.04
Bridgeport Harbor, CT	6.03	482.0	79.9	10.3	1.7	0.29	0.05	2.80	0.46	74.8	12.4	0.09	0.01
Bridgeport Harbor, CT	6.16	222.5	36.1	37.6	6.1	--	--	17.80	2.89	4.3	2.3	0.16	0.03
Ashtabula Harbor, OH	0.92	2.9	0.8	4.3	4.7	0.26	0.28	1.20	1.30	4.5	4.9	0.01	0.01
Ashtabula Harbor, OH	2.44	10.5	4.3	1.0	0.4	0.23	0.09	1.80	0.74	1.1	0.5	0.11	0.05
Ashtabula Harbor, OH	2.58	7.0	2.7	0.4	0.2	0.47	0.18	1.60	0.62	11.1	4.3	0.04	0.02
James River, VA	3.13	2.2	0.7	1.5	0.5	0.04	0.01	2.50	0.80	0.2	0.1	0.15	0.05
James River, VA	2.01	31.4	15.6	0.2	0.1	0.64	0.32	0.24	0.12	1.8	0.9	0.10	0.05
Oakland Inner Harbor, CA	3.94	16.7	4.2	6.1	1.5	0.05	0.01	1.97	0.50	28.4	7.5	--	--
Oakland Outer Harbor, CA	1.69	4.7	2.8	1.4	0.8	0.14	0.08	1.80	1.07	2.6	1.5	--	--
Hudson River, NY	4.67	8.8	1.9	0.5	0.1	0.36	0.08	15.2	3.25	55.2	11.8	0.33	0.07
Terry Creek, GA	4.87	184.0	37.8	3.1	0.6	0.09	0.02	0.60	0.12	2.0	0.4	0.10	0.02
Brunswick Harbor, GA	3.95	140.0	35.4	6.1	1.6	0.06	0.02	0.60	0.15	1.0	0.3	--	--
Houston Ship Channel, TX	1.68	3.4	2.0	48.6	28.9	0.04	0.02	0.60	0.36	2.3	1.4	0.03	0.02
Houston Ship Channel, TX	3.24	32.7	10.1	10.2	3.1	1.24	0.38	0.30	0.09	1.9	0.6	0.07	0.02
Houston Ship Channel, TX	4.22	14.2	3.4	--	--	0.10	0.02	1.30	0.31	25.1	5.9	--	--
Mean			17.5		3.3		0.13		0.64		3.8		0.08
Standard Deviation			21.0		6.3		0.12		0.86		4.0		0.11

[a]Excludes one aberrant station in Milwaukee Harbor, WI.

Table 2

REGRESSION EQUATIONS ILLUSTRATING THE RELATIONSHIP OF THE SEDIMENT-WATER PARTITION COEFFICIENT OF TRACE METALS WITH THE PERCENTAGE OF ORGANIC CARBON IN SEDIMENTS

Metal	Regression	n	r
Cu	$\log K_D = 0.33\ (TOC) + 3.28$	22	0.74[a]
Zn	$\log K_D = 0.074\ (TOC) + 3.29$	21	0.19
As	$\log K_D = -0.05\ (TOC) + 2.46$	21	-0.19
Cd	$\log K_D = 0.21\ (TOC) + 2.34$	21	0.55[a]
Pb	$\log K_D = 0.20\ (TOC) + 3.10$	22	0.47[a]
Hg	$\log K_D = 0.05\ (TOC) + 1.87$	18	0.21

[a] r value significant at $\alpha < 0.05$.

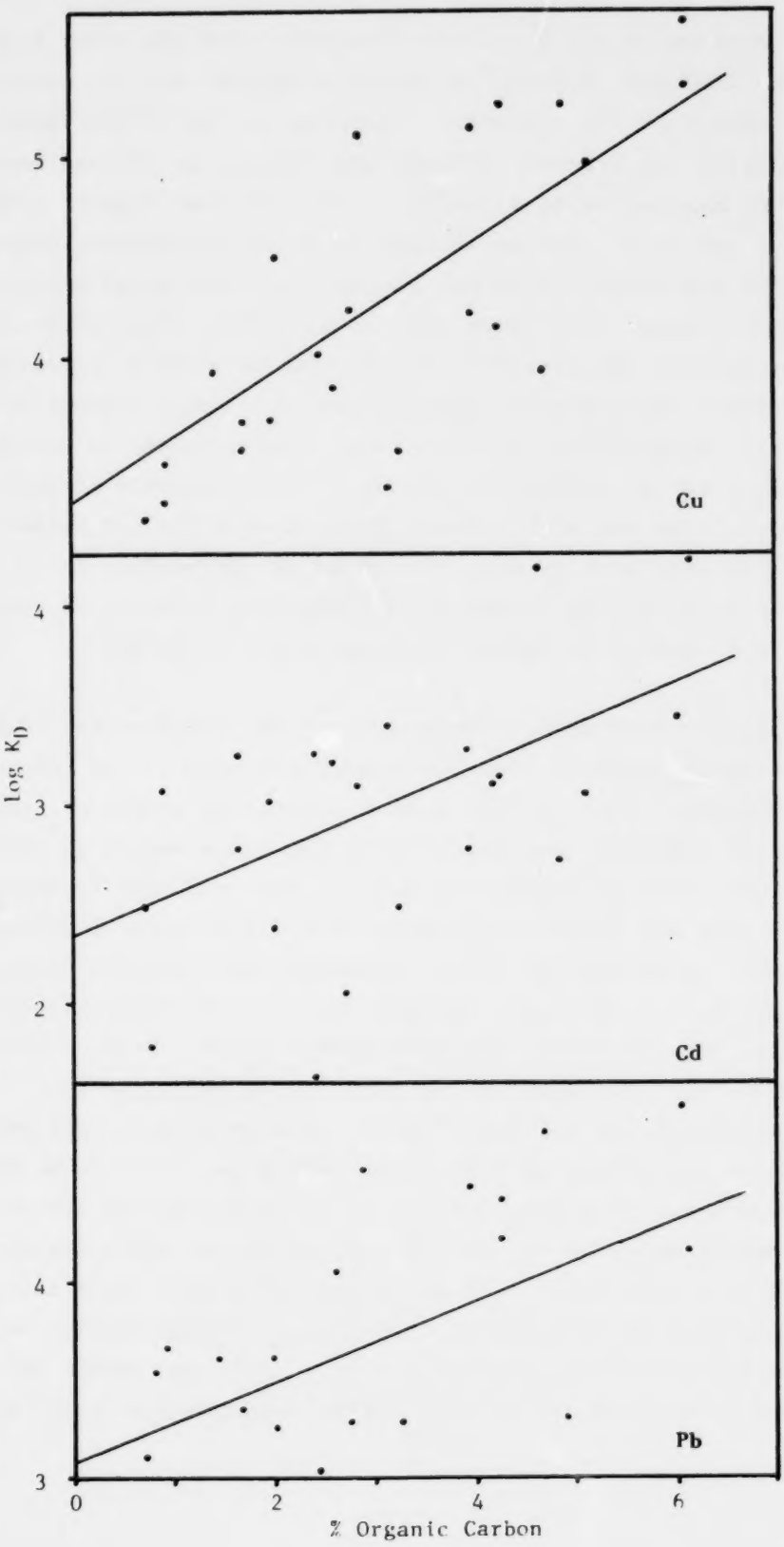

Figure 3

RELATIONSHIP BETWEEN THE SEDIMENT-WATER PARTITION COEFFICIENT AND THE SEDIMENT ORGANIC CARBON CONTENT FOR THREE TRACE METALS

(All regressions significant at $\alpha < 0.05$)

There is widespread evidence in the scientific literature that the trace metal content of marine and freshwater sediments is highly correlated with the concentration of organic carbon in the sediment. Crecilius et al. (1975) demonstrated this relationship for arsenic, antimony and mercury in the sediments of Puget Sound. This correlation is a result of the fact that organic material serves as one of the major trace metal sinks in marine sediments. Organic substances and iron plus manganese oxides dominate the trace metal sorptive properties of sediment (Jenne 1977; Jenne and Luoma, 1975). Thus sediments with a high organic content can generally be expected to exhibit a greater affinity for trace metals, and therefore have a higher K_D, than sediments with a low organic content. Normalization of trace metal concentrations to organic content, by use of K_{OC}, can be expected to provide a better estimate of partitioning, in most cases, than use of K_D alone. There is some limited evidence (Luoma and Jenne, 1975) that such an approach may not be appropriate for zinc and cobalt, but pending a thorough review of the anomalous behavior of these two metals, K_{OC} has been adopted throughout this report for all metals.

There are also biological considerations which support the normalization of K_D for trace metals to organic carbon. These are directly related to the concept of biological availability. Most of the studies addressing uptake of trace metals by sediments and organisms have demonstrated that trace metals in sediments with high concentrations of organic material are less available to deposit-feeding organisms than are those in sediments with little organic matter. For example, the uptake of mercury by both a polychaete and a deposit-feeding shrimp was significantly less when the sediment was rich in organic matter than when the mercury was associated with iron-oxides (Luoma, 1974). Iron-oxide bound cadmium was more available to the clam, Macoma balthica, than was organic-associated cadmium (Luoma and Jenne, 1975). Similar effects have been demonstrated for silver and copper as well (Luoma and Jenne, 1975; Jenne and Luoma, 1975). Consideration of organic content in the derivation of sediment criteria for trace metals makes the criteria more stringent for sediments with lower concentrations of organic matter. This is consistent with observations of increased bioavailability of trace metals in low organic environments. However, there are exceptions to this generality such as zinc and cobalt which demonstrate increased bioavailability in high organic environments (Luoma and

Jenne, 1975). Such exceptions may warrant further examination and may possibly require modifying the approach to sediment criteria for select trace metals.

3.2.2 Synthetic Organic Compounds

Partition coefficients for the synthetic organic priority chemicals were calculated from empirical relationships of K_{OC} versus K_{OW}, the latter quantity denoting the octanol-water partition coefficient for a given organic chemical. K_{OW} is a good indicator of the relative accumulation potential of a chemical in the environment, specifically in biotic components, since it reflects the influence of molecular properties on the affinity of the chemical for an organic matrix. K_{OW} is also useful in estimating a chemical's relative sorption potential on solid surfaces when coated with natural organic matter as is the case with aquatic sediments. As mentioned earlier, there is ample evidence that the affinity of an organic compound for sedimentary particles is determined to a large degree by the concentration of organic carbon in the sediment, hence the use of K_{OC} versus K_{OW} relationships is a highly advantageous technique for estimating sediment water partition coefficients for a variety of organic chemicals.

Estimation of K_{OW}

K_{OW} is usually determined experimentally by adding a small amount of the chemical to an octanol-water mixture, allowing the system to reach equilibrium, and then measuring the concentration of the chemical in each phase. Reliable estimates of K_{OW} have also been obtained by chromatographic techniques (Veith and Morris, 1978), from other solvent-water partition coefficients (Leo and Hansch, 1971), and by the fragment constant method (Hansch and Leo, 1979). K_{OW} values obtained by at least one of the above methods are available for most organic compounds. The K_{OW} values used in this study were obtained primarily from Karickoff (1981) and Kenaga and Goring (1980).

Development of K_{OC}/K_{OW} Relationships

K_{OC} values have been determined experimentally for about 70 organic compounds (Kenaga and Goring, 1980; Karickhoff, 1981). Figure 4 and Table 3 illustrate the various regression equations that have been used to predict K_{OC} from K_{OW}. The variability among the regression equations is a result of the different

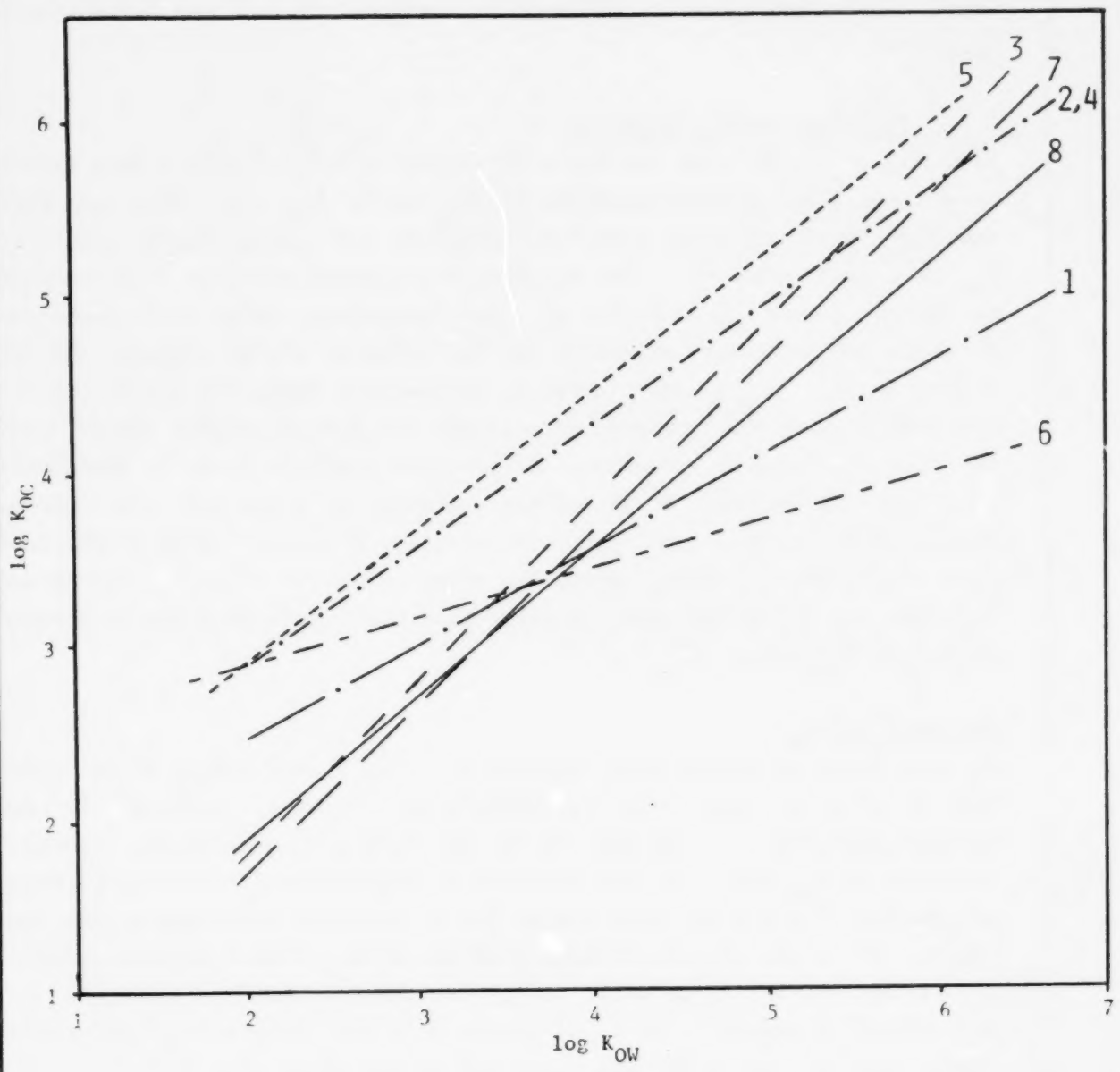

Figure 4

REGRESSION EQUATIONS FROM THE LITERATURE USED TO PREDICT K_{OC} FROM K_{OW}
(Numbers on each regression line refer to the equation numbers in Table 3)

Table 3

REGRESSION EQUATIONS FROM THE LITERATURE FOR THE ESTIMATION OF K_{OC} FROM K_{OW}
(Modified from Lyman et al., 1982)

No.	Regression	Number of Compounds Considered	r	Chemical Class	Reference
1	$\log K_{OC} = 0.544 \log K_{OW} + 1.377$	45	0.86	Pesticides	Kenaga & Goring, 1980
2	$\log K_{OC} = 0.937 \log K_{OW} - 0.006$	19	0.97	Aromatics, polynuclear aromatics, triazines, dinitroaniline herbicides	Brown et al., in prep.
3	$\log K_{OC} = 1.00 \log K_{OW} - 0.21$	10	1.00	Mostly aromatic & polynuclear aromatics	Karickhoff et al., 1979
4	$\log K_{OC} = 0.94 \log K_{OW} + 0.02$	9	--	Triazines and dinitroaniline herbicides	Lyman et al., 1982
5	$\log K_{OC} = 1.029 \log K_{OW} - 0.18$	13	0.95	Variety of herbicides, insecticides, and fungicides	Rao & Davidson, 1980
6	$\log K_{OC} = 0.524 \log K_{OW} + 0.855$	30	0.92	Substituted phenyl ureas and alkyl N-phenylcarbamates	Briggs, 1973
7	$\log K_{OC} = 0.989 \log K_{OW} - 0.346$	5	1.00	Aromatic & polynuclear aromatic hydrocarbons	Karickhoff, 1981
8	$\log K_{OC} = 0.843 \log K_{OW} + 0.158$	19	0.96	Priority pollutants	Present report

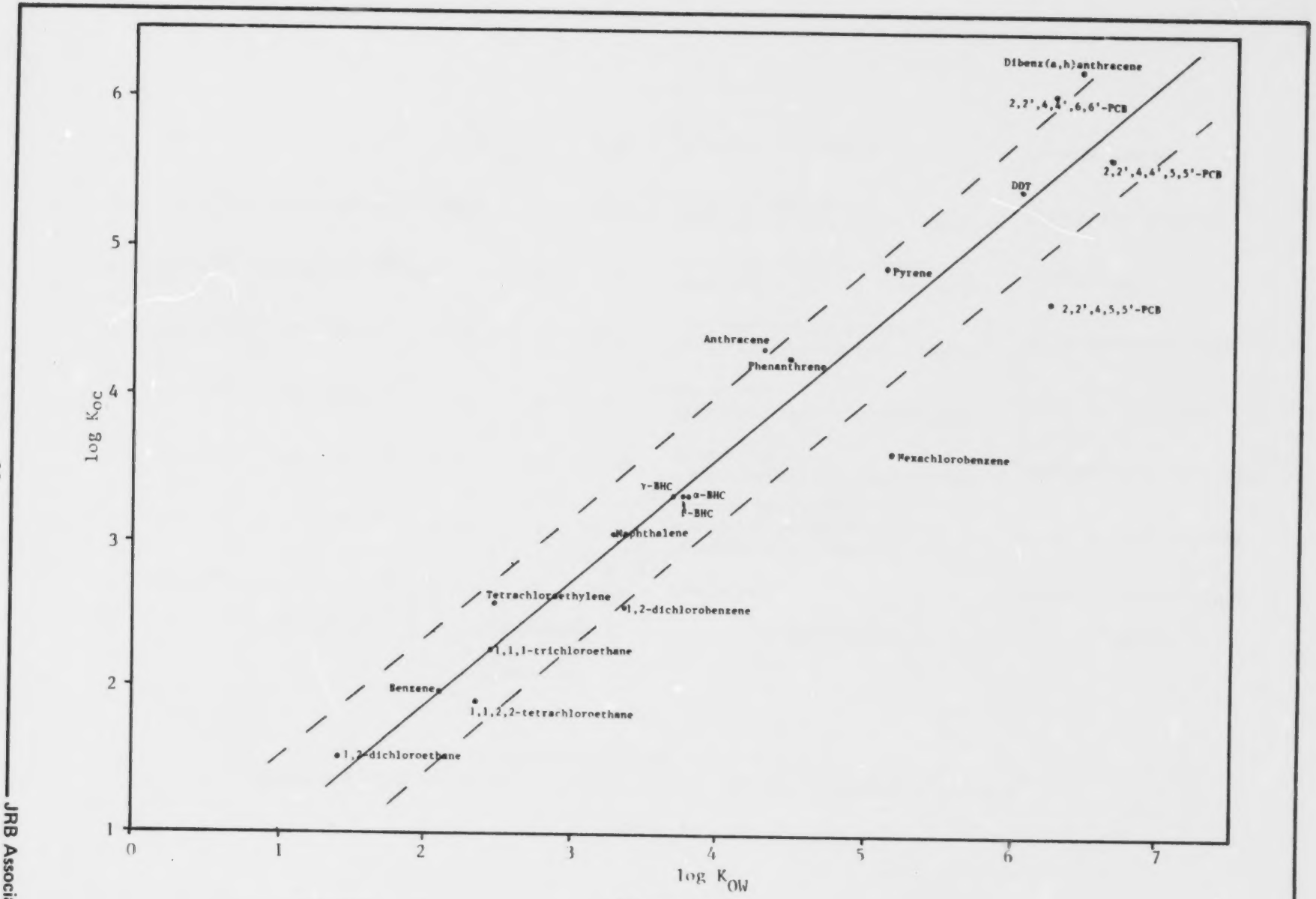

Figure 5
REGRESSION OF K_{OC} and K_{OW} AS DERIVED FOR THE 19 PRIORITY POLLUTANTS SHOWN
Uncertainty limits on either side of the regression line are the standard errors

chemical compounds used to derive each regression. For example, regression six was derived for phenylureas and phenylcarbamates, neither of which are relevant to environmental quality of Puget Sound. In order to obtain a K_{OW}-K_{OC} regression most applicable to those compounds measured in Puget Sound sediments, only the chemicals which were among the 129 EPA priority pollutants were considered. Nineteen priority organic compounds consisting primarily of polynuclear aromatic hydrocarbons and chlorinated hydrocarbons were identified for which literature values of K_{OW} and K_{OC} were available. From those compounds a regression equation was derived and the uncertainty in the computed K_{OC} values estimated. The results are shown in Figure 5. Estimates of K_{OC} obtained by this regression were calculated to have a standard error of about $\overset{\times}{\div}$ 3 ($\pm$0.48 on log scale) though the error is somewhat greater ($\overset{\times}{\div}$ 3.1) at very high or very low values of K_{OW} and lower ($\overset{\times}{\div}$ 2.8) for K_{OW} values in the middle of the distribution. A comparison of measured K_{OC} values from the literature with those predicted by the regression is shown in Table 4 for the 19 priority pollutants on which the regression was based. On the average, predicted K_{OC} were within a factor of 2 (0.3 on log scale) of the measured values. The large deviation noted for hexachlorobenzene and pentachlorobiphenyl (nearly by a factor of 10) suggests either that these compounds exhibit anomalous chemical behavior or that the experimentally measured K_{OC} values may be in error.

The predictive capability of the K_{OW} - K_{OC} regression was tested for an additional 45 non-priority pollutants for which literature K_{OC} values were available. These data are superimposed on the regression obtained from the priority pollutants as shown in Figure 6. The predicted K_{OC} values from the regression are compared to the literature values in Table 5. In general the predictive capability of the regression is satisfactory for a wide variety of compounds. The K_{OC} values for polynuclear aromatics and chloro-s-triazines were particularly close to the literature values, generally within a factor of 2 to 2.5 (0.3 - 0.4 on log scale). The K_{OC} values for organophosphates and phenylureas were the least reliable, with an average error of about a factor of 5.

3.3 CALCULATION OF SEDIMENT CRITERIA

Sediment criteria for both the trace metal and priority organic contaminants considered in this study were computed using equation (4), Section 3.1.

Table 4

COMPARISON OF K_{OC} VALUES PREDICTED BY THE K_{OW}-K_{OC} REGRESSION WITH MEASURED K_{OC} VALUES FROM THE LITERATURE FOR THE 19 PRIORITY POLLUTANTS ON WHICH THE REGREESION IS BASED
(All literature values from either Karickhoff, 1981 or Kenaga and Goring, 1980)

Compound	log K_{OW} (literature)	log K_{OC} (literature)	log K_{OC} (predicted)	Error
Aromatic hydrocarbons				
Anthracene	4.40	4.32	3.87	-0.45[a]
Pyrene	5.18	4.88	4.52	-0.36
Phenanthrene	4.52	4.24	3.97	-0.27
Naphthalene	3.31	3.03	2.94	-0.09
Dibenz(a,h)anthracene	6.50	6.22	5.64	-0.58[a]
Benzene	2.12	1.95	1.95	-0-
			Average	0.29
Halogenated hydrocarbons				
1,2-dichloroethane	1.45	1.51	1.38	-0.13
1,1,1-trichloroethane	2.47	2.25	2.24	-0.01
1,1,2,2-tetrachloroethane	2.39	1.90	2.17	+0.27
Tetrachloroethylene	2.53	2.56	2.29	-0.27
1,2-dichlorobenzene	3.39	2.54	3.02	+0.48[a]
Hexachlorobenzene	5.23	3.59	4.57	+0.98[a]
DDT	5.98	5.38	5.20	-0.18
Y-BHC (Lindane)	3.72	3.30	3.29	-0.01
α-BHC	3.81	3.30	3.37	+0.07
β-BHC	3.80	3.30	3.36	+0.06
			Average	0.25
Halogenated biphenyls				
2,2',4,5,5'-pentachlorobiphenyl	6.30	4.63	5.47	+0.84[a]
2,2',4,4',5,5'-hexachlorobiphenyl	6.72	5.62	5.82	+0.20
2,2',4,4',6,6'-hexachlorobiphenyl	6.34	6.08	5.50	-0.58[a]
			Average	0.54

[a]Error exceeds one standard error.

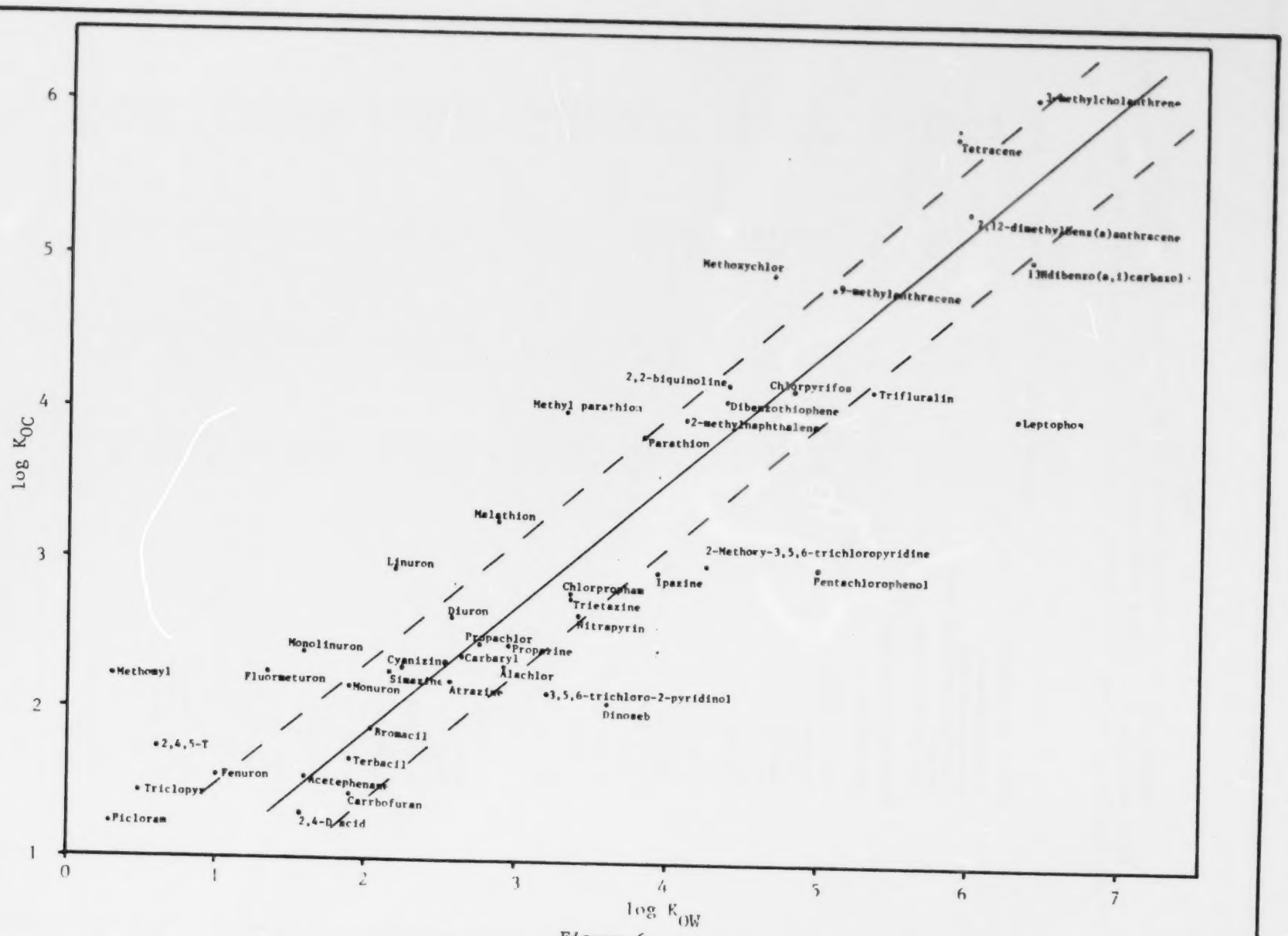

Figure 6

K_{OC} AND K_{OW} VALUES FOR 45 NON-PRIORITY POLLUTANTS SUPERIMPOSED ON THE REGRESSION DERIVED FOR PRIORITY POLLUTANTS

Table 5

COMPARISON OF K_{OC} VALUES PREDICTED BY THE K_{OC}-K_{OW} REGRESSION WITH MEASURED K_{OC} VALUES FROM THE LITERATURE FOR 45 NON-PRIORITY POLLUTANTS
(All literature values from either Karickhoff, 1981; or Kenaga and Goring, 1980)

	log K_{OW} (Literature)	log K_{OC} (Literature)	log K_{OC} (Predicted)	Error
Aromatic hydrocarbons				
9-methylanthracene	5.07	4.81	4.43	-0.38
2-methylnaphthalene	4.11	3.93	3.62	-0.29
7,12-dimethylbenz(a)anthracene	5.98	5.35	5.20	-0.15
Tetracene	5.90	5.81	5.13	-0.68*
3-methyl cholanthrene	6.42	6.09	5.57	-0.52*
			Average	0.40
Halogenated hydrocarbons				
Methoxychlor	4.68	4.90	4.10	-0.80*
Chloro-s-triazines				
Atrazine	2.56	2.17	2.32	+0.15
Propazine	2.94	2.41	2.64	+0.23
Simaxine	2.16	2.25	1.98	-0.27
Trietazine	3.35	2.74	2.98	+0.24
Ipazine	3.94	2.91	3.48	+0.57*
Cyanazine	2.24	2.26	2.05	-0.21
			Average	0.28
Carbamates				
Carbaryl	2.64	2.36	2.38	+0.02
Carbofuran	1.89	1.46	1.75	+0.29
Chlorpropham	3.06	2.77	2.74	-0.03
Methomyl	0.30	2.20	0.41	-1.79*
			Average	0.53
Organophosphates				
Malathion	2.89	3.25	2.59	-0.66*
Parathion	3.81	3.89	3.37	-0.52*
Methylparathion	3.32	3.99	2.96	-1.03*
Chlorpyrifos	4.81	4.13	4.21	+0.08
Leptophos	6.31	3.97	5.47	+1.50*
			Average	0.76
Phenyl ureas				
Diuron	2.57	2.60	2.32	-0.28
Fenuron	1.00	1.55	1.00	-0.55*
Linuron	2.19	2.93	2.00	-0.93*
Monolinuron	1.60	2.38	1.51	-0.87*
Monuron	1.90	2.14	1.76	-0.38
Fluometuron	1.34	2.24	1.29	-0.95*
			Average	0.66
Miscellaneous				
2,4-D acid	1.56	1.30	1.47	+0.17
Picloram	0.30	1.23	0.41	-0.82*
2,4,5-T	0.60	1.72	0.66	-1.06*
Triclopyr	0.48	1.43	0.56	-0.87*
Trifluralin	5.34	4.14	4.66	+0.52*
2-methoxy-3,5,6-trichloropyridine	4.28	2.96	3.77	+0.81*
Nitrapyrin	3.41	2.62	3.03	+0.41
3,5,6-trichloro-2-pyridinol	3.21	2.11	2.86	+0.75*
13Hdibenzo(a,i)carbazole	6.40	6.02	5.55	-0.47*
2,2'biquinoline	4.31	4.02	3.79	-0.23
Dibenzothiophene	4.38	4.05	3.85	-0.20
Acetophenone	1.59	1.54	1.50	-0.04
Terbacil	1.89	1.66	1.75	+0.09
Bromacil	2.02	1.86	1.86	-0-
Dinoseb	3.69	2.09	3.27	+1.18*
Pentachlorophenol	5.01	2.95	4.38	+1.43*
Alachlor	2.92	2.28	2.62	+0.34
Propachlor	2.75	2.42	2.48	+0.06
			Average	0.53

*Error exceeds one standard error.

3.3.1 Trace Metals

Sediment criteria were calculated based on the K_{OC} values derived from Brannon et al. (1980) and the available water quality criteria for protection of saltwater aquatic life. The results are summarized in Table 6 together with the corresponding water quality criteria. The standard deviation reflects the uncertainty in the K_{OC} values. Though many of the trace metal water quality criteria presented are draft criteria, they were chosen as representative of the most current toxicological information available.

3.3.2 Synthetic Organic Compounds

The derived sediment criteria for 47 priority organic compounds measured in sediments of the Central Basin of Puget Sound (Pavlou et al., 1983) are presented in Table 7. These criteria were based on the K_{OC} values estimated from regression equation 8, shown in Table 3. Again the associated standard error reflects the uncertainty in the K_{OC} values as discussed in Section 3.3.1. Though both acute and chronic sediment criteria are presented when available, the chronic value is recommended in order to insure adequate protection of marine life. Specifically, chronic sediment criteria are more appropriate than acute values since: (1) sediment contaminant concentrations reflect long-term conditions and do not demonstrate the extreme temporal variability of water column contaminant concentrations; and (2) benthic organisms often lack the mobility required to escape a contaminated environment and therefore are susceptible to impacts resulting from long-term chronic exposure. However, no chronic criteria are currently available for the majority of organic compounds and in these cases only acute sediment criteria have been presented in Table 7. It may be possible to establish an estimated chronic criteria by one of two methods: (1) for those compounds having a freshwater chronic criterion this may be used as an estimate of the saltwater criterion; and (2) the chronic criterion can be estimated from the acute criterion using the general "rule of thumb" that the acute:chronic ratio is 100:1. Both approaches warrant further consideration but a review of the toxicological literature is necesary to determine if one or both approaches would be suitable for establishment of interim sediment criteria guidelines.

It is important to note that for many compounds EPA has not established a water quality criterion but only identifies the lowest concentration at which

Table 6

SUMMARY OF DATA USED TO DEVELOP SEDIMENT CRITERIA FOR TRACE METALS

Chemical (Trace Metals)	EPA Water Quality[a] Criteria (µg/ℓ)		$(K_{OC} \pm \sigma) \times 10^4$	Sediment Criteria $C_{S/CR/OC} \times 10^{-6}$ g/g o.c.	
	Acute	Chronic		Acute (σ)	Chronic (σ)
Arsenic^{+3}[b]	120	63	1.3 ± 1.2	1,600 (±1,400)	820 (±790)
Cadmium[b]	38	12	6.4 ± 8.6	2,400 (±3,300)	770 (±1,000)
Copper[b]	3.2	2.0	170 ± 210	5,400 (±6,700)	3,400 (±4,200)
Lead[b]	220	8.6	38 ± 40	84,000 (±88,000)	3,300 (±3,400)
Mercury[b] (inorganic)	1.9	0.10	0.8 ± 1.1	15 (±21)	0.8 (±1.1)
Zinc	170	58	33 ± 63	56,000 (±110,000)	19,000 (±38,000)

[a] Acute water quality criteria are the maximum permissible concentrations for protection of saltwater aquatic life as obtained from the Federal Register, Vol. 45, No. 231 (1980) or, in the case of some trace metals from draft criteria documents soon to be released. Chronic criteria are 24-hr average concentrations when obtained from the Federal Register or 30-day average when obtained from draft criteria documents.

[b] Draft criteria documents.

Table 7
SUMMARY OF DATA USED TO DEVELOP SEDIMENT CRITERIA FOR ORGANIC COMPOUNDS

Compound	Water Quality Criteria (µg/ℓ)		log K_{OW}[a]	K_{OC}[b,c]	Sediment Criteria $C_{S/CR/OC} \times 10^{-6}$ g/g o.c.	
	Acute	Chronic			Acute[d]	Chronic[d]
Phenol	2,900[e]		1.46	24	70	
Acenaphthene*	475[e]	355[e]	4.17	4,700	2,300	1,650
Anthracene*	150[e,f]		4.40	7,400	1,100	
Benzo(a)anthracene*	150[e,f]		5.61	37,000	5,500	
Benzo(a)pyrene*	150[e,f]		6.31	300,000	45,000	
Benzo(b)fluoranthene*	150[e,f]		6.57	500,000	75,000	
Benzo(k)fluoranthene*	150[e,f]		6.84	840,000	125,000	
Fluoranthene	20[e]	8[e]	5.33	45,000	900	360
Fluorene*	150[e,f]		4.18	4,800	700	
Naphthalene*	1,175[e]		3.31	890	1,050	
Phenanthrene*	150[e,f]		4.52	9,300	1,400	
Acenaphthalene*	150[e,f]		4.07	3,900	600	
Dibenz(a,h)anthracene	150[e,f]		6.50	160,000	24,000	
Isophorone	6,450[e]		1.67	37	240	
Nitrobenzene	3,340[e]		1.83	50	165	
1,2-dichlorobenzene	80[e]	65[e]	3.40	1,100	90	70
1,4-dichlorobenzene	80[e]	65[e]	3.37	1,000	80	65
2,6-dinitrotoluene	290[e]		2.05	77	22	
Benzo(g,h,i)perylene	150[e,f]		7.23	1,800,000	270,000	
Chrysene*	150[e,f]		5.61	77,000	11,500	
Indenopyrene	150[e,f]		7.66	4,100,000	600,000	
Pyrene*	150[e,f]		5.18	33,000	4,950	
Butylbenzyl phthalate	1,472[e,f]		4.05	3,700	5,500	
Di-n-butyl phthalate	1,472[e,f]		5.20	35,000	50,000	
Di-octyl phthalate	1,472[e,f]		9.20	82,000,000	120,000,000	
Diethyl phthalate	1,472[e,f]		1.40	22	32	
Dimethyl phthalate	1,472[e,f]		1.61	33	49	
Hexachlorobutadiene	16[e]		3.74	2,000	32	
α-BHC	0.17[e]		3.81	2,300	0.49	
Lindane*	0.16[g]		3.72	1,950	0.31	
DDD*	1.8[e]		6.03	180,000	325	
DDE*	7[e]		5.74	99,000	700	
DDT*	0.13[g]	0.001[g]	5.98	160,000	21	0.16
Aldrin*	1.3[g]		—	400[h]	0.52	
2-PCB*		0.014[f,g]	4.81	4,600		0.064
3-PCB*		0.014[f,g]	5.58	73,000		1.0
4-PCB*		0.014[f,g]	5.75	100,000		1.4
5-PCB*		0.014[f,g]	6.30	370,000		5.2
6-PCB*		0.014[f,g]	6.57	500,000		7
Benzene	2,550[e]	350[e]	2.12	97	245	34
Ethylbenzene	265[e]		3.15	650	140	
Methyl chloride	6,000[e]	3,200[e]	0.91	8	48	
Methylene chloride	6,000[e]	3,200[e]	1.25	16	95	50
Tetrachloroethylene	5,100[e]	225[e]	2.53	200	1,000	45
Toluene	3,150[e]	2,500[e]	2.21	100	315	250
Trichloroethylene	1,000[e]		2.42	160	160	
1,2-Dichloropropane	5,150[e]	1,520[e]	2.28	120	600	180

*Criteria for these compounds tested against measured concentrations in Puget Sound (see Section 4.3).

[a] K_{OW} values from Callahan et al. (1979); Dexter (1976); Kenaga and Goring (1980); Veith et al. (1980).

[b] Derived from regression 8 in Table 3.

[c] Standard error of K_{OC} values $\times \div$ 3, 95% confidence interval $\times \div$ 10.

[d] Standard error of sediment criteria $\times \div$ 3, 95% confidence interval $\times \div$ 10.

[e] Not nationally adopted water quality criteria, but rather one-half the lowest concentration at which toxic effects have been noted as reported in the Federal Register, Vol. 45, No. 231 (1980). Actual criteria, when established, are likely to be different.

[f] Based on the class criteria for polynuclear aromatic hydrocarbons (300 µg/ℓ), phthalate esters (2,944 µg/ℓ), or polychlorinated biphenyls (0.014 µg/ℓ).

[g] EPA Water Quality Criteria. Acute criteria are the maximum permissible concentrations for protection of saltwater aquatic life as obtained from the Federal Register, Vol. 45, No. 231 (1980). Chronic criteria are the 24-hour average concentrations from the same document.

[h] K_{OC} value obtained from Karickoff (1981). No literature value of K_{OW} is available to permit derivation of K_{OC} by the regression equation.

adverse biological effects have been reported. In these cases, a sediment criterion has been determined on the basis a water quality "criterion" established at one half the lowest concentration causing adverse biological effects. The procedure closely parallels the protocol followed in development of water quality criteria in which a Final Acute Value (FAV) designed to protect 95 percent of a diverse group of species is determined, and the criteria is established at one half of the FAV. This approach has been adopted as an interim attempt to estimate the concentration at which a water quality criterion may eventually be established. However, it is important to recognize that for some compounds the lowest concentration causing adverse effects is based on a very limited toxicological data base. In these cases the estimated water quality "criterion" used in this report could be substantially different from the value eventually established. Therefore, these "criteria" may be inadequate to insure protection of marine life, and therefore any violation of these "criteria" could be of serious consequence.

The EPA water quality criteria for the PCBs, phthalates and polynuclear aromatic hydrocarbons are class criteria based on the cumulative concentration of all members of the class. In the derivation of the sediment quality criteria, it has been necessary to apply the class criterion to each member of the class individually, since each has a unique K_{OC}. In environments where one class member comprises the majority of the sediment burden of the class, this approach should prove adequate. However, if numerous class constituents are significantly enriched, a safe threshold for the class as a whole may be exceeded even though no individual constituent violates the criteria.

3.4 LIMITATIONS

Although the advantages of using the equilibrium partitioning approach were presented earlier in this report, there are a number of limitations inherent in the approach that must be considered as well. These are discussed below together with their implications in the use of the equilibrium partitioning approach.

3.4.1 Lack of Comprehensive Water Quality Criteria

The equilibrium partitioning approach has the advantage of providing a simple mechanism whereby water quality criteria can be adapted to sediment quality

criteria. However, this fact is also a limitation in that sediment criteria can only be established for those compounds for which water quality criteria are available. For the majority of synthetic organic contaminants, EPA has not yet established water quality criteria. This problem was addressed by using one half the lowest concentration causing adverse effects in cases where definitive water criteria were not available. As additional water quality criteria are established by EPA, sediment criteria can be readily determined for the same compounds.

3.4.2 Synergism and Antagonism

Synergistic or antagonistic interactions among contaminants can result in a mixture of contaminants having either a greater or lesser toxicity than would be expected simply on the basis of the toxicities of the individual contaminants. Thus there is some danger that although all individual contaminants may be at concentrations below criteria, synergistic interactions may still induce adverse biological impacts. While sediment criteria should ultimately account for synergistic effects, there is at present no way to do so given our current state of knowledge. The proposed criteria derived by the equilibrium partitioning approach represent an interim solution of immediate applicability. The only means currently available to address synergism is by using bioassay methods. Therefore the optimal approach to insure protection of marine life may be one whereby bioassays and the partitioning method may be used concurrently.

3.4.3 Level of Uncertainty in the Sediment Criteria

Unlike federal water quality criteria, the sediment criteria proposed in this report are presented as a mean with a specified level of uncertainty. This uncertainty is a result of our inability, based upon the current state of knowledge, to accurately predict the degree of partitioning of a contaminant between sediment and water. The water quality criteria is considered as a fixed value, therefore the level of uncertainty associated with the sediment criteria is entirely a consequence of the uncertainty in the K_{OC} value.

A number of options are available to environmental managers in attempting to implement a sediment criterion with a given level of uncertainty. One possible approach is to establish an alert level at the mean sediment criterion

and a maximum permissible sediment contaminant concentration at the upper bound of the uncertainty limit. A sediment in which the concentration of contaminant falls between the mean criterion for that contaminant and the upper bound of the uncertainty level could be identified for further studies such as bioassays in order to demonstrate the absence of any environmental danger. For those sites at which a contaminant concentration exceeds the upper bound of the uncertainty limit, immediate corrective action may be required. This upper uncertainty limit could be established either at one standard deviation from the mean or at the 95% confidence limit depending upon the degree of conservatism desired.

3.5 ASSUMPTIONS

A number of necessary assumptions have been incorporated in developing the equilibrium partitioning approach to sediment criteria. These are listed in Sections 3.5.1 through 3.5.5 below. Section 3.5.6 summarizes these assumptions and provides qualitative estimates of the impact on the criteria should the assumptions be violated.

3.5.1 Validity of The Equilibrium Assumption

The basic premise in the equilibrium assumption is that the distribution of a contaminant at the sediment-water interface is under thermodynamic equilibrium and the ratio of the contaminant concentration in the solid phase to its concentration in the aqueous phase is a constant. This assumption should generally hold except as the concentration of the contaminant approaches saturation at which point the solid phase:aqueous phase ratio may no longer be constant. However, this is not expected to significantly impact the equilibrium approach to sediment criteria since the criterion for a contaminant should be violated long before saturation is reached. It is possible that in the natural environment under certain physical/chemical conditions, kinetically controlled adsorption may be operable, which may violate the equilibrium assumption. These processes are complex and poorly understood (Lyman et al., 1982).

3.5.2 Normalization of K_{OC} to Organic Content

Throughout this report organic carbon content of the sediments has been considered a major environmental variable in determining the sediment-water partitioning for both trace metals and synthetic organic compounds. Justification

for using K_{OC} rather than K_D was provided in Section 3.1 for the organics and Section 3.2.1 for the trace metals. Though this appraoch is considered generally applicable, it may be necessary to modify it for a few select trace metals as discussed earlier (e.g., zinc). Such a determination would require careful review of existing literature and potentially additional experimental work.

3.5.3 Influence of Environmental Variables on K_{OC}

Although as discussed above, organic carbon appears to be an important variable influencing sediment-water partitioning other physical/chemical factors may affect the partitioning process. A brief discussion of the most important variables is presented below.

Reduction/Oxidation Potential and pH

Most of the organic contaminants of greatest environmental concern are the base-neutral compounds. These chemicals are relatively insensitive to changes in the reduction/oxidation (redox) potential or pH. However, for the trace metals, a change in the redox potential or pH can result in a change of oxidation state and/or chemical speciation and thereby dramatically influence the sediment-water partitioning and toxicity of the metal. The approach used in this report to derive K_{OC} values for trace metals was designed to take into account the dependency of partitioning on a variety of environmental variables, while recognizing our inability to predict these dependencies with our current limited of knowledge. Trace metal K_{OC} values were determined for a wide variety of environments (diversity of site locations) and then used to calculate an overall mean and standard deviation. Therefore, the variability in K_{OC} induced by the site specific reduction/oxidation conditions or pH is assumed to be incorporated into the estimate of the uncertainty about the mean.

Temperature

This physical variable may have a small influence on the partitioning of a chemical between sediment and water. For most contaminants, an increase in temperature usually results in a decrease in K_{OC}, though there are exceptions. Lyman et al. (1982) calculated that a 10% decrease in K_{OC} could be typically expected for an increase in temperature from 20°C to 30° C. An 18% increase would be expected for a temperature decrease from 20° C to 5° C. Considering

that the values of K_{OC} used in the derivation of sediment criteria have a standard error of a factor of 3, the uncertainty introduced by variations in temperature is negligible.

Salinity

This variable may have some influence on K_{OC}, though as with temperature the impact is minimal. Karickhoff et al. (1979) reported a 15% increase in K_D with a change in salinity from 0 to 20%. Salinity may be of greater importance for the organic acids, though the extent of this importance is dependent upon the relationship of pH to the pK_a of the acid (Pionke and Chesters, 1973).

The salinity of the deep water layer in Puget Sound is fairly uniform and constant, although some variability is expected in the nearshore environments, specifically in the urban embayments. This variability may reflect small-scale circulation phenomena and tidal mixing. It should be pointed out that the salinity in the water column may not be as important to the equilibrium partitioning approach as variations of ionic strength within the interstitial water.

Dissolved Organic Matter

Natural dissolved organic matter (DOM) consists primarily of refractory polyelectrolytes resulting from the degradation of biological materials (Christman and Minear, 1971). The DOM forms stable solutions which can scavenge trace metals or organic chemicals either through electrostatic interactions (ion-ion, ion-dipole or ligand) or through hydrophobic interactions with non-polar sites of the DOM. At the sediment-water interface these interactions may enhance the contaminant levels in the aqueous phase with the net result being a reduction in the partition coefficient value.

The implication of this phenomenon is twofold (1) under these conditions, the derived criterion should be a lower value, and (2) if direct uptake from interstitial water is the dominant mechanism of bioaccumulation, contaminant bioavailability will be increased. To this date these processes have neither been investigated nor well understood due to their complexity. It should also be noted that any elucidation of the chemical interactions at the sediment-water interface will be further complicated by the effect of pH or ion content

changes which in turn would influence the degree of ionization, the effective charge density and the chemical form of the DOM.

Particle Size

The importance of particle size in determining the magnitude of the sediment-water partition coefficient is largely a function of organic carbon content. Sediments with a high percentage of silts and clays generally have a high organic carbon content and consequently have a higher sediment-water partition coefficient (K_D). Sandy sediments have little organic carbon and have a lower partition coefficient. Grain-size dependent variations of the partition coefficient as a consequence of organic content is accounted for by expressing the partition coefficient as a K_{OC} value rather than K_D.

There is some limited evidence that surface area and other factors related to grain size may affect the partitioning beyond that which could be explained solely on the basis of organic carbon content. Karickhoff et al. (1979) examined the partitioning of pyrene and methoxychlor on a variety of particle size fractions. While K_{OC} remained essentially constant for all size fractions from coarse silt to clay, the sand fraction exhibited a K_{OC} only 20% of that derived from the fines. For sediments with a high percentage of sand (> 95%) some correction of the K_{OC} value may be required to account for particle size effects (Karickhoff, 1981).

As it pertains to sediment criteria, the work of Karickhoff suggests that in very sandy sediments, pollutants would have a lower affinity for sediment particles than predicted on the basis of a generalized K_{OC}. The sediment quality criteria for very sandy sediments would therefore be too high to provide adequate protection. Further laboratory work and field verification is necessary in order to define the dependence of K_{OC} on particle size. In the event such a dependence is established sediment criteria could easily be adjusted on the basis of the percentage of sand as well as on the organic carbon content.

3.5.4 Bioavailability of Contaminants at the Sediment-Water Interface

The soluble fraction of a contaminant is generally readily available for uptake by marine organisms (Jenne and Luoma, 1975; Roesijadi et al., 1978).

Therefore it is a relatively simple matter to establish a permissible concentration of a contaminant in water. However, the development of sediment quality criteria is complicated by the fact that the bioavailability of a contaminant in sediments is strongly dependent upon specific geochemical associations. Although the sediment quality criteria make the assumption that all of the contaminant in the sediment is in a bioavailable form, this is in fact rarely the case, for the total amount of a contaminant does not necessarily reflect its potential for biological effects.

As an example, Luoma and Jenne (1975) exposed clams to a variety of metal-contaminated artificial sediments including iron oxides, manganese oxides, calcium carbonate and an organic detritus. The concentration factors for the trace metals in clam tissue varied over two orders of magnitude depending upon the type of sediment in which they were held. The dependence of bioavailability on geochemical associations between a contaminant and sediments is probably most critical and best documented for trace metals but may be of significance for organics as well.

The question of bioavailability is not adequately treated in the sediment quality criteria proposed, since the criteria are given for the total contaminant in the sediment. It would be advantageous if criteria could be developed only for the bioavailable portion of the contaminant rather than the total contaminant load. Such an approach would require additional research but is not infeasible. A number of investigators have used sequential leaching techniques to extract only select fractions of the total contaminant load in sediments (Brannon et al., 1980; Vangenechten et al., 1983). If an extraction procedure can be found which will reliably identify the bioavailable portion of the total contaminant load, then a sediment criteria can be expressed in terms of the amount of the contaminant extracted by that procedure.

3.5.5 Applicability of Water Quality Criteria to Benthic Organisms

EPA water quality criteria for the protection of saltwater aquatic life are designed to insure that the concentration of contaminants in the aqueous phase do not exceed a level which would induce adverse effects in marine biota. In adapting the water quality criteria to sediment criteria, two assumptions have been made: (1) the permissible concentration of a contaminant in the aqueous

phase, as defined by the water quality criteria, are within safe limits for the protection of benthic organisms; and (2) ingestion of sediment-bound contaminants by benthic deposit-feeders does not result in a greater uptake of contaminants than that predicted by exposure to dissolved contaminants alone.

It is important to consider if benthic organisms would be afforded adequate protection by application of water quality criteria to the interstitial water. EPA water quality criteria are established on the basis of bioassays conducted with representatives of a number of phyla. Though the test organisms are typically free-swimming (e.g., fish, shrimp) a number of benthic invertebrate species have been included. Stephan et al. (1983) provides a list of marine species used in toxicity tests and includes a large number of polychaetes, molluscs and benthic crustaceans. Since benthic organisms have been employed in the derivation of criteria, these criteria should provide adequate protection to these animals. Additionally, there is no evidence to indicate that, as a group, benthic organisms are any more sensitive to dissolved contaminants than organisms in the overlying water column.

The role of uptake of sediment-bound contaminants by ingestion is a critical question in application of any type of sediment criteria. Not only are benthic organisms exposed to contaminants dissolved in the interstitial water, but they may ingest sediment particles during feeding activities and absorb sediment-bound contaminants through the gut wall. The concentration of contaminants on the ingested particle may be several orders of magnitude greater than in the interstitial water, but the amount of particle-associated contaminant available to an organism during passage through the gut depends upon the strength of the contaminant-sediment bond.

The equilibrium partitioning approach to sediment criteria does not discount the potential for uptake of contaminants by ingestion but only assumes that the contaminant body burden of the organism is independent of the route of uptake. If a system containing sediment, water and an organism is allowed to come to equilibrium, the level of a contaminant in each component should reach a constant, predictable concentration. For the purposes of the partitioning approach, it is assumed to be irrelevant whether the organism obtains the contaminant from the interstitial water or ingested sediment since the equilibrium body burden would be the same regardless of the route of uptake.

The experimental evidence available to support this assumption is very limited due to the experimental difficulties involved in assessing the route of pollutant uptake. The limited evidence seems to indicate that for the transuranium elements (plutonium, americium) and some trace metals, ingestion of sediment does not significantly increase the body burden above that attributable to absorption from the interstitial water (Renfro, 1973; Beasley and Fowler, 1976; Miramand et al., 1982; Vangenechten et al., 1983). Uptake of other trace metals and polychlorinated biphenyls on the other hand, may occur largely by ingestion of sediment as shown by a number of laboratory studies (Luoma and Jenne, 1975; Courtney and Langston, 1978; Fowler et al., 1978). The study of Fowler et al. (1978) is especially significant since the animals were allowed to reach equilibrium with the surroundings. In this case, organisms permitted to ingest sediment attained body burdens of PCB two orders of magnitude greater than those exposed to PCB in the dissolved form. It should be pointed out, however, that available experimental evidence is inadequate to either prove or disprove the assumptions of the equilibrium partitioning approach regarding the importance of contaminant uptake by ingestion. For most of the studies, the evidence presented is inconclusive or the experimental artifacts introduced are so great as to bring into question the applicability of the results to natural systems. Additional research is necessary to adequately evaluate the importance of pollutant uptake by ingestion of sediment.

3.5.6 Summary of Assumptions

Since the equilibrium partitioning concept represents a new and unique approach to sediment criteria, the analyses and evaluations presented in this report have focused on the identifications of all assumptions inherent in the approach. None of the assumptions are considered significant enough to invalidate the approach, but it was deemed essential to assess their potential impact. They have been discussed at considerable length both to insure against misuse of the approach and to direct further efforts of refinement.

The assumptions presented above are summarized in Table 8 and cross-referenced with the report section in which they are discussed. For each assumption a potential for violation has been given which represents the likelihood (high, medium or low) that the assumption may prove invalid by further investigation.

Table 8

ASSUMPTIONS OF THE EQUILIBRIUM APPROACH AND THEIR POTENTIAL FOR VIOLATION

Assumption	Report Section	Potential for Violation of Assumption	Impact of Violation on Proposed Criteria
Sediment-water partitioning of a contaminant is at equilibrium	3.5.1	Medium	Criteria may be too conservative. Violations would be site-specific and source-specific, not compound-specific.
Magnitude of partition coefficient dependent upon sediment organic content	3.5.2	Low (organics) High (metals)	At low organic carbon levels the proposed criteria would be too conservative. At high organic carbon levels the criteria would be liberal.
Variations in the redox potential and pH will not impact criteria	3.5.3	Low (base-neutral organics); High (metals and some organics)	The effect of redox potential on trace metal partitioning has been largely accounted for by empirical derivation of partition coefficients. In some instances, the redox potential may effect partitioning beyond the level already accounted for. Field verification is needed to determine potential impact on criteria.
Independence of partitioning on temperature	3.5.3	Low	Typical environmental variations in temperature will effect criteria by 10% or less.
Independence of partitioning on salinity (ionic strength)	3.5.3	Medium	For most contaminants of environmental concern, variations in salinity typical of marine waters will have a negligible impact on the criteria. Variation in salinity between fresh and saltwater could effect criteria by about 25%. An increase in ionic strength of interstitial water would result in a higher criteria value therefore criteria may be too conservative.
Independence of partitioning on dissolved organic matter (DOM)	3.5.3	Medium	Criteria would be lowered as DOM increases. Criteria may be too liberal.
Particle size is not important in determining partitioning other than as a covariate with organic carbon	3.5.3	Low	Evidence to date is very limited but in very sandy sediments criteria may be too liberal.
Entire contaminant burden of sediments is in a bioavailable form	3.5.4	High	If a fraction of the contaminant is not bioavailable, the proposed criteria would be too conservative.
Water quality criteria are appropriate for benthic organisms	3.5.5	Low	Criteria would be either too liberal or too conservative depending upon toxicant sensitivity of benthic organisms.
Ingestion of sediment-bound contaminants by deposit-feeders does not increase contaminant body burden above levels attained by exposure to the dissolved contaminant fraction	3.5.5	Medium	Criteria would be too liberal if assumption were violated.

Many of the assumptions are unavoidable because of the inadequacy of our current state of knowledge. In these cases the potential for violation represents a "best guess" by the authors based on the limited information available. Should any of the assumptions be violated, the potential impact on the proposed criteria is also given. The potential impact is quantified in some cases (e.g., temperature and salinity) though for most assumptions it is impossible to go beyond a qualitative statement of potential impact at this time.

4.0 FEASIBILITY TESTING IN PUGET SOUND

4.1 FORMAT OF PRESENTATION

In order to compare a measured contaminant concentration in Puget Sound with the sediment criterion for that compound it is most convenient to use equation (5) Section 3.1 and represent criteria limits as a plot of contaminant concentration $C^X_{S/CR}$ versus percent organic carbon (Figure 7). These plots (diagonal lines) can be produced showing both the acute and chronic criteria as well as the bounds for the uncertainty limits around the criteria. For the purpose of this report, the plots from now on will be referred to as the "criteria-graph" for the contaminant of concern. Specifically, the criteria-graphs are determined by converting the organic carbon normalized criteria ($C^X_{S/CR/OC}$ of Tables 6 and 7) to equivalent dry weight normalized concentrations ($C^X_{S/CR}$) at a given organic carbon content. For example, the chronic $C^X_{S/CR/OC}$ value for Pb is 3,300 ppm. For sediments with 10% organic carbon (0.1 g o.c./g sediment) the permissible concentration of lead in the sediments for protecting the biota from chronic toxicity is 330 ppm. The criteria-graphs present the permissible sediment contaminant concentrations at any specified organic carbon content.

The contaminant concentrations and organic carbon content at sites of concern can be plotted on the graph and readily compared to a criterion. Those stations to the left of a criterion line are below the criterion, while those to the right of the line exceed criterion. In the example of Figure 7, Station A is below the chronic criterion for lead, Station B exceeds the mean criterion but is within one standard deviation and station C exceeds the criterion by more than one standard deviation. The example also illustrates the importance of considering organic carbon content as well as contaminant concentration in assessing the extent of contamination. Station A is the only station below criterion despite the fact that it has a greater contaminant burden on a dry weight basis than Station B.

A couple of points are important to bear in mind in evaluating Figure 7 and similar figures throughout Section 4.3. First, in determining the K_{OC} for trace metals, the standard deviation of the K_{OC} was found to be greater than the mean value (see Table 1). When the uncertainty of the K_{OC} is incorporated

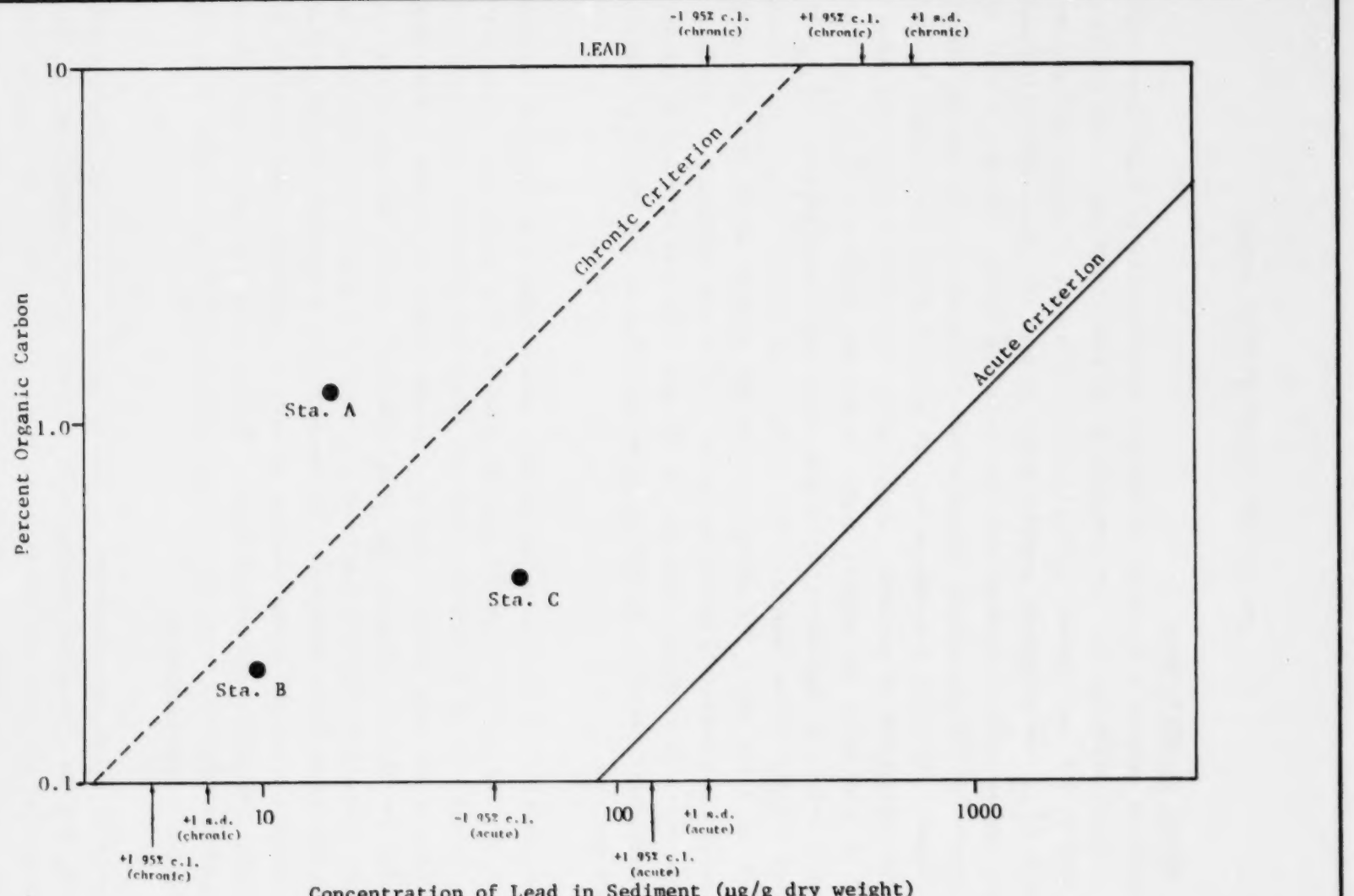

Figure 7

PRESENTATION FORMAT FOR COMPARISON OF SEDIMENT CRITERIA
WITH ACTUAL MEASURED CONTAMINANT CONCENTRATION

in the derivation of sediment criteria for trace metals, the criteria minus one standard deviation lies below a concentration of zero. Therefore it is only possible to show the criteria plus one standard deviation on the criteria-graphs for trace metals. A similar problem is not apparent in the criteria-graphs for synthetic organics since the criteria for organics were derived on the basis of the K_{OW} - K_{OC} regression in which the standard error of K_{OC} was less than the mean. Therefore both an upper and lower standard error can be shown for the organics.

Secondly, the 95% confidence interval is equally as valid as the standard deviation or standard error as a measure of uncertainty around the criteria. Both the 95% confidence interval and the standard deviation are shown in Figure 7 but only the standard deviation or standard error are shown in later figures in Section 4.3 in order to simplify the presentation. It is possible to calculate 95% confidence intervals using the methods shown in Sokal and Rohlf (1981) and numerous other statistics books. For all the trace metals, the 95% confidence intervals would appear on the criteria-graphs at approximately the same position relative to the mean and standard deviation as is shown in Figure 7. For the synthetic organics, the 95% confidence intervals would appear on the criteria-graphs as symmetrical about the mean, located at a distance approximately two standard errors from the criteria value.

4.2 TRIAL DATA SETS

To test the applicability of the derived criteria values to Puget Sound, two independent data sets were selected that had sufficient ancillary information to allow direct comparisons of contaminant sediment concentrations to the numerical criteria values computed by the equilibrium partitioning approach.

1. The first set of test data used was that published by Malins et al. (1980), encompassing six embayments in Puget Sound (Commencement Bay, Elliott Bay, Sinclair Inlet, Port Madison, Case Inlet, and Budd Inlet). These subregions are known to vary in degree of contamination and therefore provided a wide enough spectrum of contaminant concentrations in sediments to determine the extent of sediment criteria violations. The data used in the analyses are presented in Appendix A of this report and extracted from Appendix D (Results of Chemical Analyses) Tables D-2, D-3, D-4, D-5 and D-7 from Malins et al. (1980).

2. Sediment criteria were also tested by comparison with the concentration of contaminants in sediments measured in Elliott Bay and within the vicinity of the West Point Outfall as published in the Metro/TPPS Draft Report (Pavlou et al., 1983). These measurements constitute the most recent information on toxicant accumulation in sediments in this urban environment. The concentration data of the priority compounds used are presented in Appendix B of this report and were extracted from Appendices 7A.1, 7A.2 and 7B.1 of the Metro/TPPS Report, Volume I. The zone designations for the specific subregions used were: Area EE, Central Elliott Bay; Area B, South Elliott Bay; Area C, Eastern Elliott Bay; and Area D, Northeast Elliott Bay/Denny CSO area. The West Point sampling sites used were those included in Area F.

The Metro/TPPS data did not include measurements of sediment organic carbon content taken concurrently with the samples for chemical analysis. However, since the percentage of silt and clay particles in sediments is highly correlated with the organic carbon content, it is possible to estimate organic carbon content from grain size data. Grain size and organic carbon content data from Malins et al. (1980) was used to develop a regression which defined the relationship between these variables (Figure 8). Metro/TPPS grain size data was then used to estimate the organic carbon content of these sediments (Appendix C). While this approach is the only alternative when organic carbon data is lacking, it should be noted that the procedure adds an additional degree of uncertainty in determination of the appropriate sediment criteria.

4.3 COMPARISON OF MEASURED CONCENTRATIONS WITH DERIVED CRITERIA

The sediment contaminant concentrations in the trial data sets of Malins et al. (1980) and Metro/TPPS were compared to criteria levels using the graphical approach discussed above in Section 4.1. The data from each test station were illustrated as a scatterplot on a graph of sediment contaminant concentration vs. percent organic carbon. The criteria-graphs were superimposed upon these same plots using the solid and dashed lines to represent acute and chronic criteria, respectively, as demonstrated in Figure 7. The results of the comparison of measured concentrations with criteria are illustrated for the trace

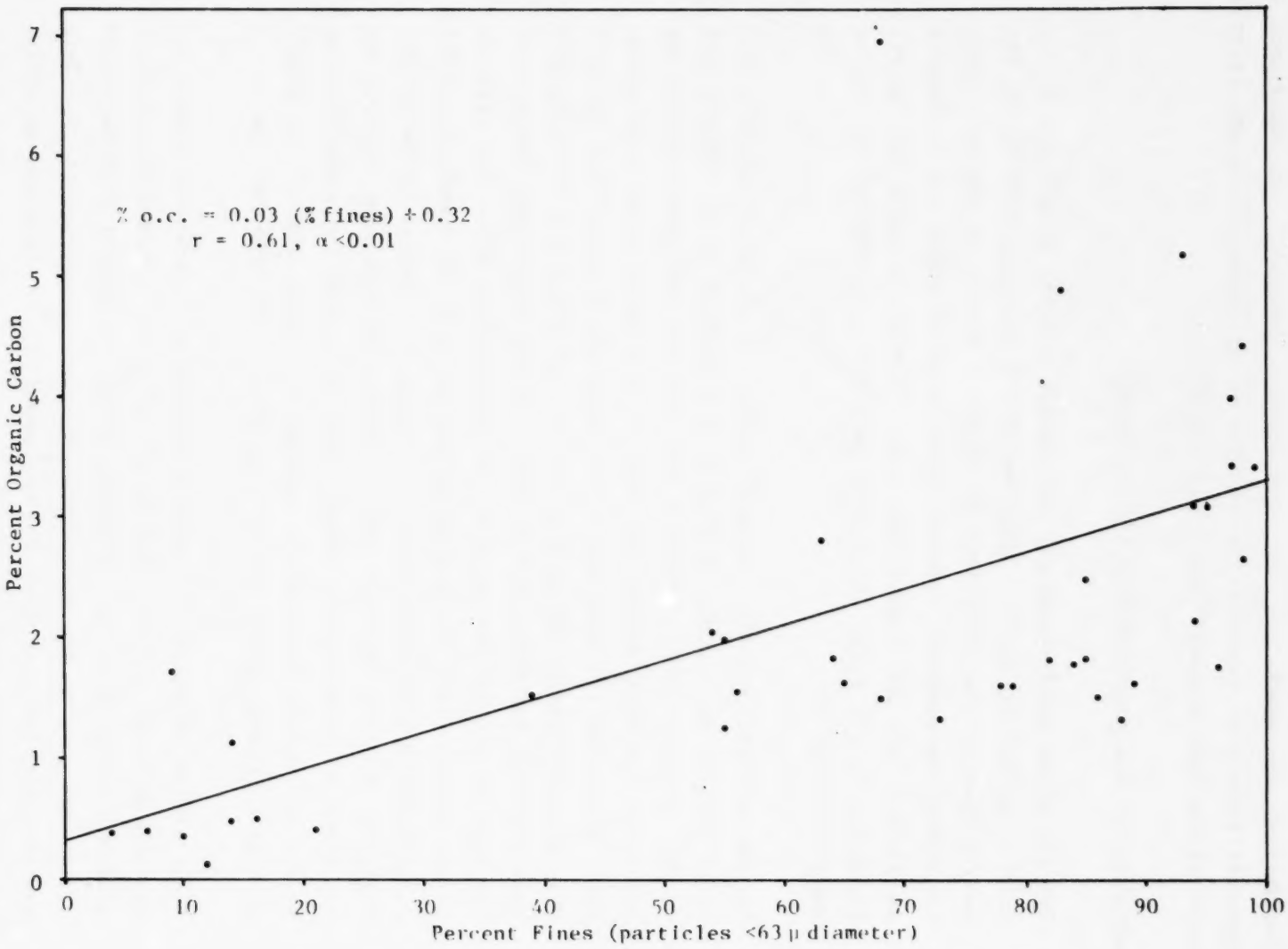

Figure 8 .

REGRESSION USED TO ESTIMATE THE ORGANIC CARBON CONTENT OF SEDIMENTS FROM THE PERCENTAGE OF FINES
(Data from Malins et al., 1980)

metals (Figures 9-14) and for the synthetic organics (Figures 15-23). Illustrations are shown only for nine organic compounds. An additional 14 compounds were also examined as designated in Table 7, though observed concentrations were generally well below criteria.

Examination of the graphs reveals the following:

- For the trace metals examined, the chronic criteria is exceeded in the order: Hg>Pb>Cu>As>Zn>Cd. Acute values are exceeded primarily by the metals Hg>Cu>As; no violations are apparent for Cd, Zn and Pb. Among the subregions examined, proposed criteria are exceeded most frequently in Elliott Bay and Commencement Bay. Chronic criteria for Hg are exceeded in all areas suggesting that the criteria for Hg may be unrealistically low.

- For the synthetic organic compounds tested, the absence of chronic criteria for most contaminants prevented an evaluation of the significance of the observed levels. However, for PCBs and DDT chronic values are obviously exceeded within the most contaminated urban embayments. Acute values for the remainder of the chemicals examined were exceeded only by fluoranthene, phenanthrene and pyrene within a fairly localized area north of the West Point Outfall. It should be noted however that for most of the polynuclear aromatic hydrocarbons (PNAs) the criteria values used are both class criteria and one-half the lowest concentrations at which toxic effects have been noted as reported in the Federal Register, Vol. 45, No. 231 (1980). Individual compound criteria may therefore be substantially lower, thus increasing the probability of violations within the regions examined. Similar limitations should also be considered in the use of class chronic criteria for PCBs.

- Most of the measured contaminant concentrations which exceed the derived sediment criteria fall within plus one standard deviation or standard error of the mean criteria values as computed from the uncertainty assigned to the partition coefficient quantities (K_{OC}). This may have some implication on the enforceability of the numerical action levels computed by this approach (see Section 3.4.3).

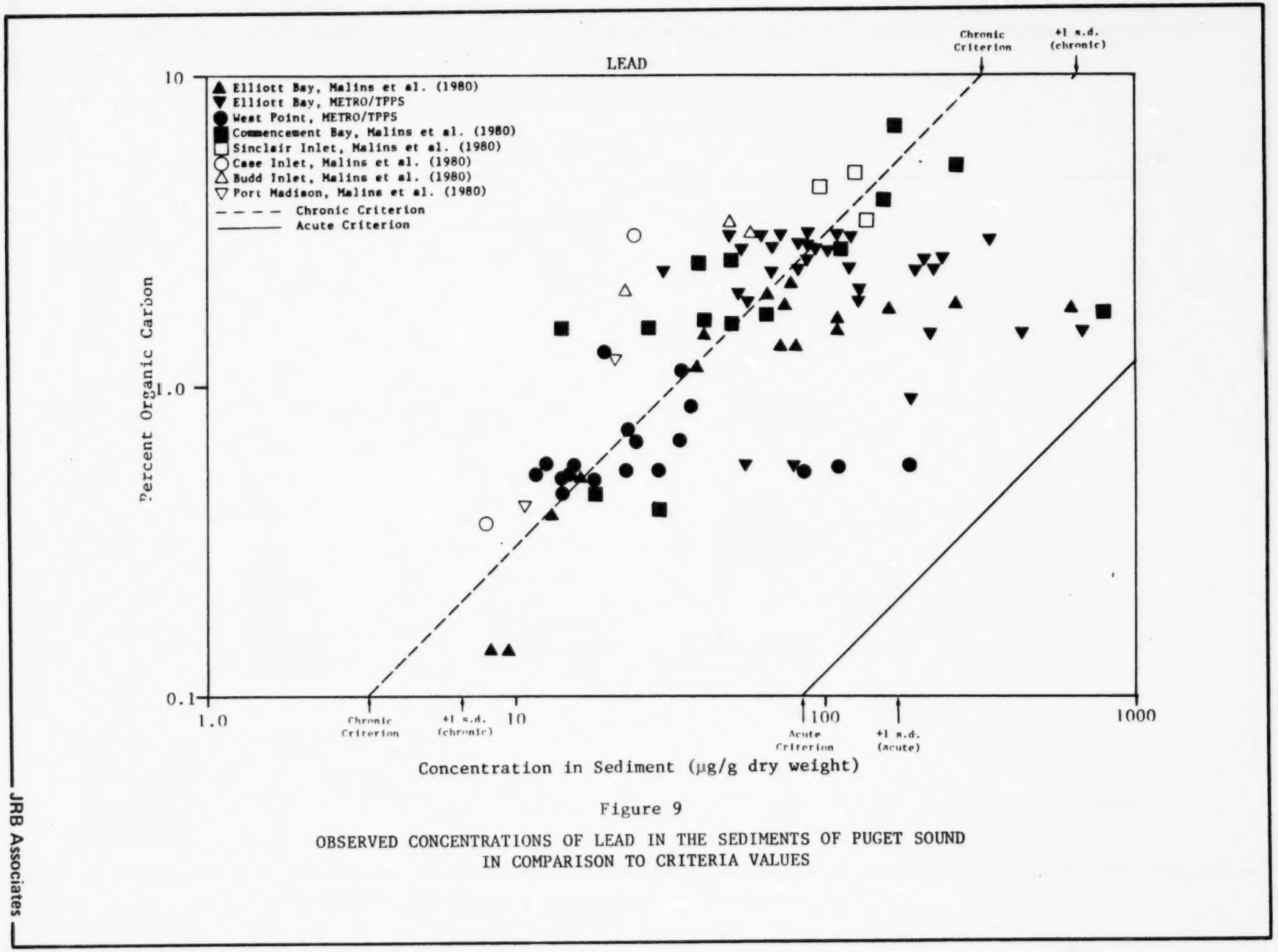

Figure 9

OBSERVED CONCENTRATIONS OF LEAD IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

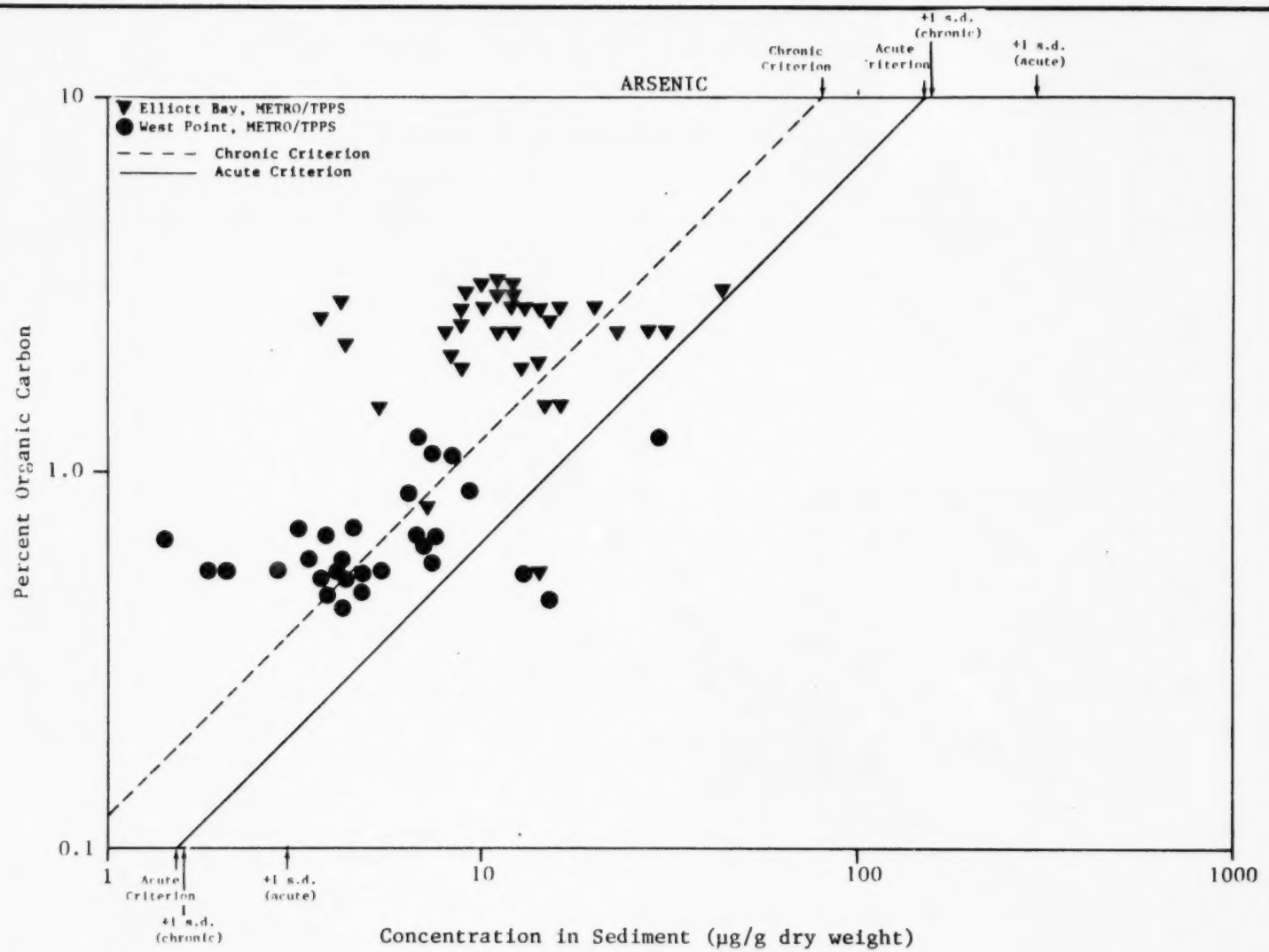

Figure 10

OBSERVED CONCENTRATIONS OF ARSENIC IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES
(Arsenic concentrations reported by Malins et al., 1980, are suspiciously high and were not included)

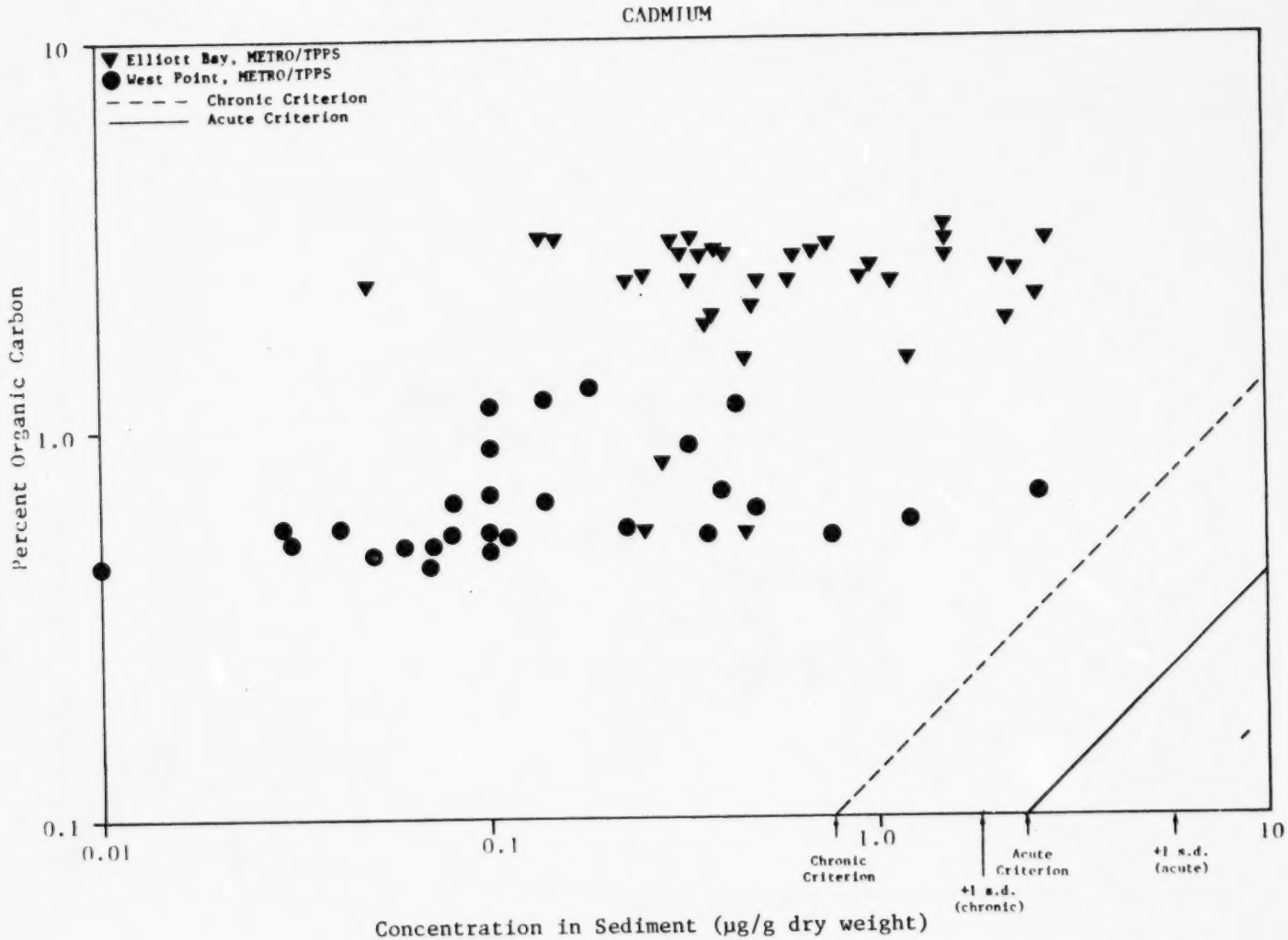

Figure 11

OBSERVED CONCENTRATIONS OF CADMIUM IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES
(Cadmium concentrations reported by Malins et al., 1980, are suspiciously high and were not included)

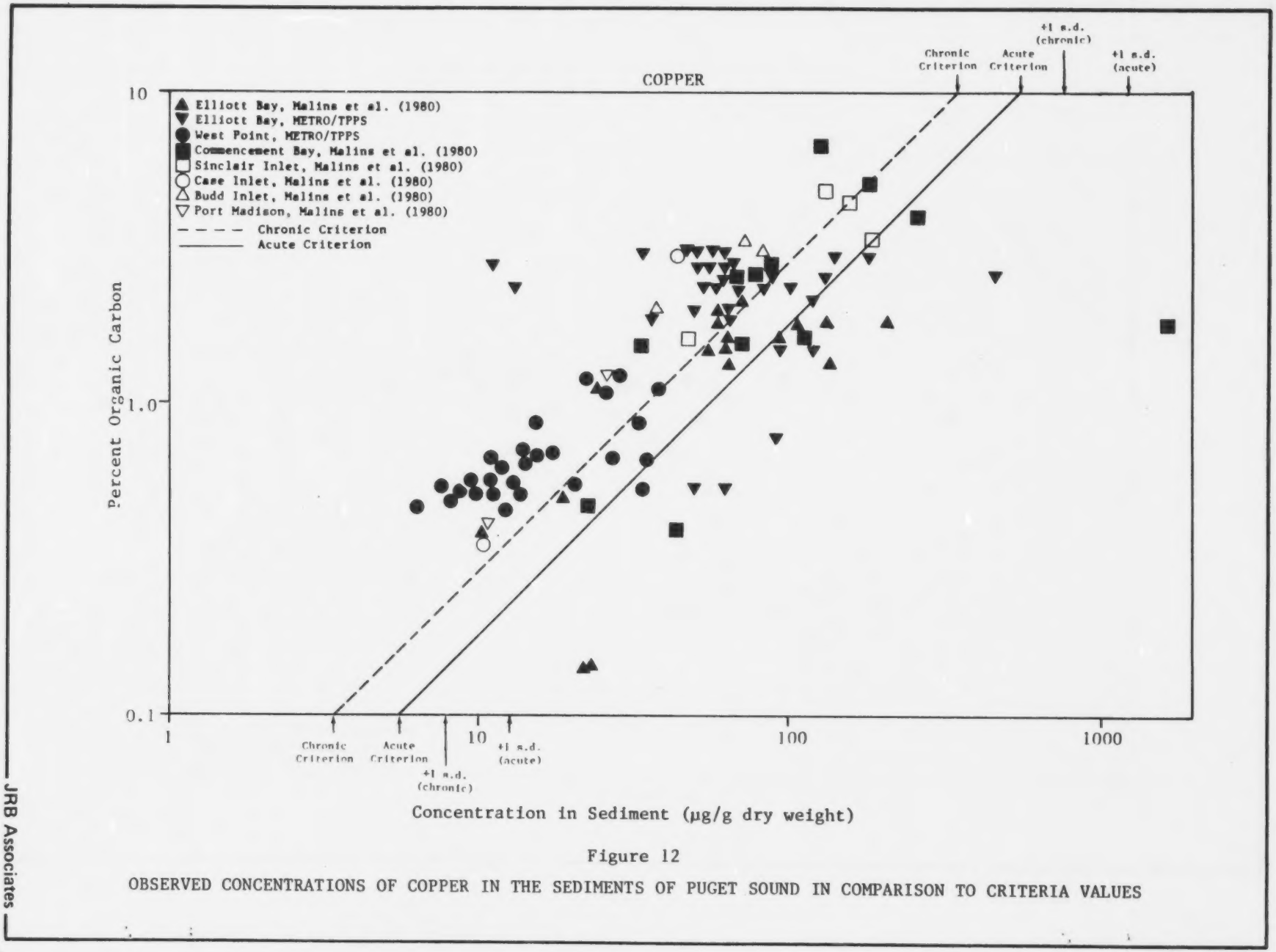

Figure 12

OBSERVED CONCENTRATIONS OF COPPER IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

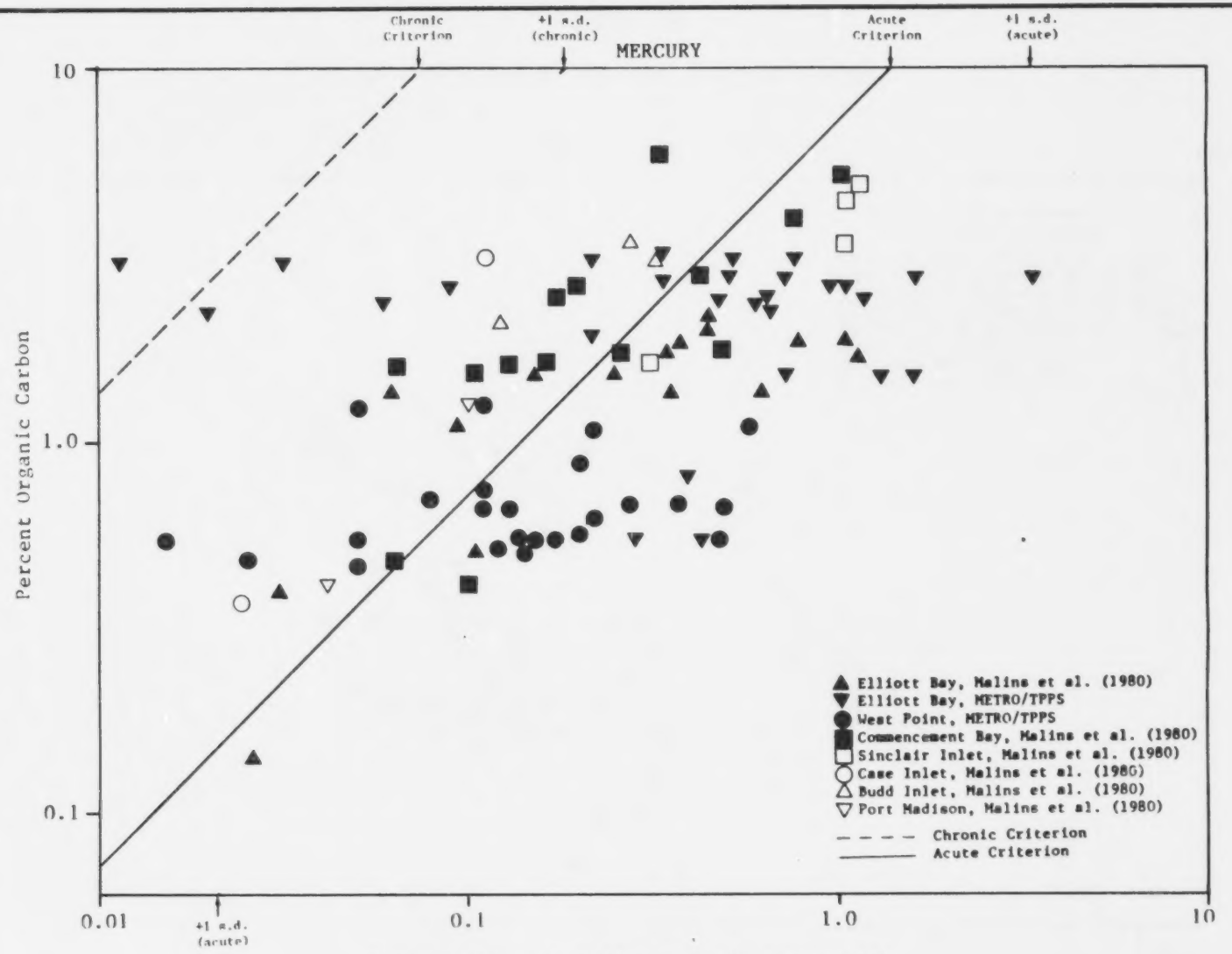

Figure 13

OBSERVED CONCENTRATIONS OF MERCURY IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

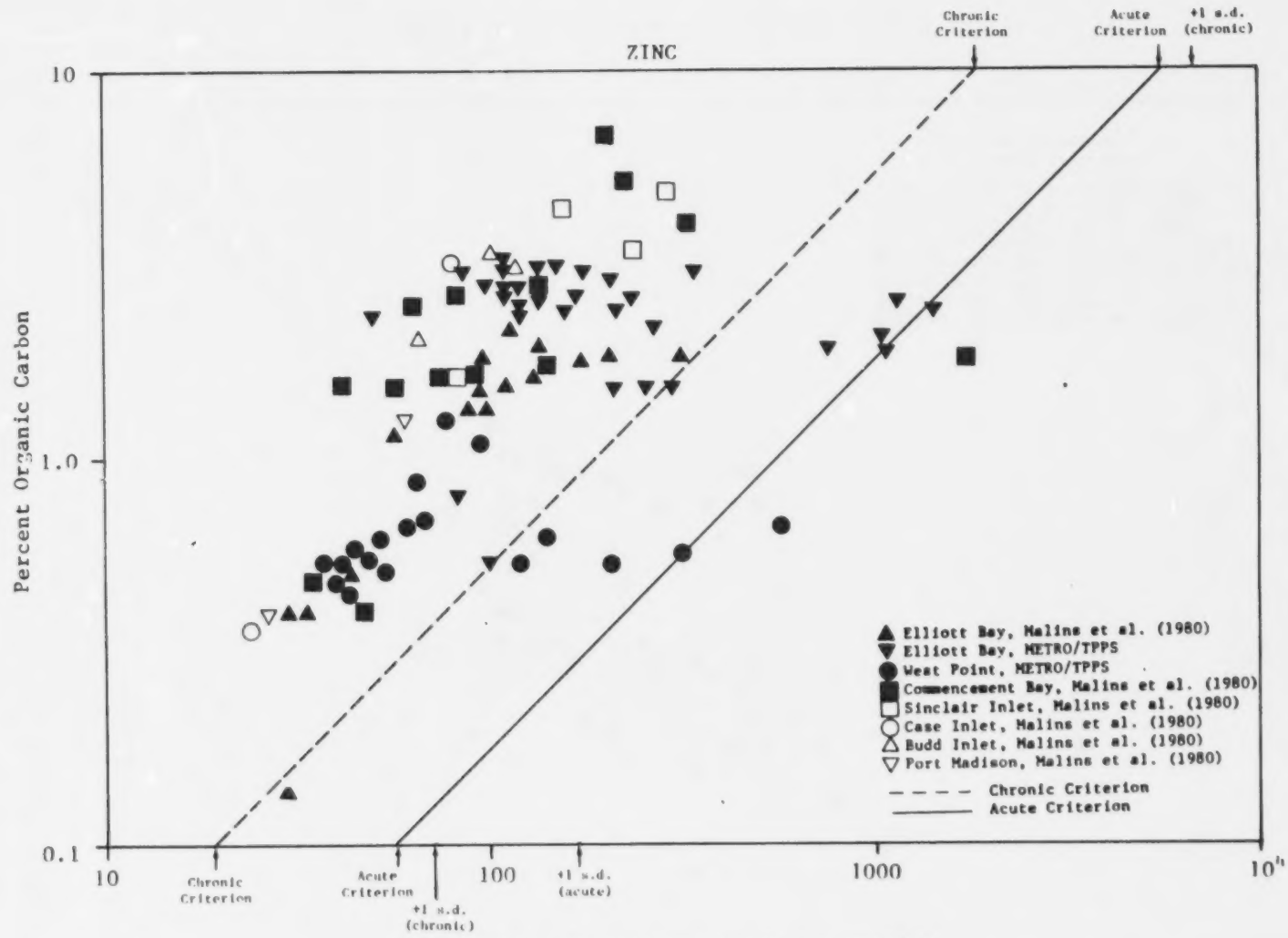

Figure 14.

OBSERVED CONCENTRATIONS OF ZINC IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

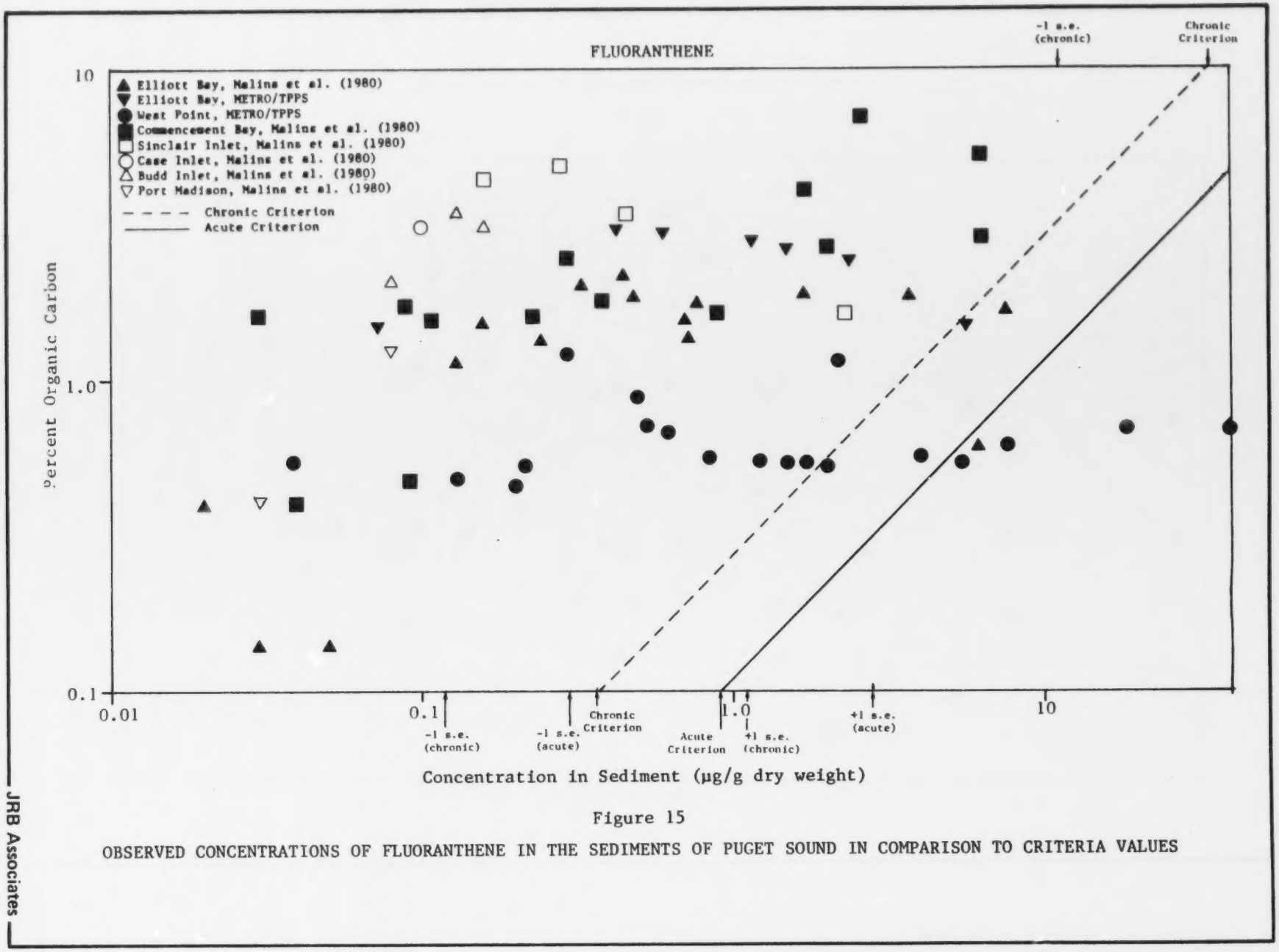

Figure 15

OBSERVED CONCENTRATIONS OF FLUORANTHENE IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

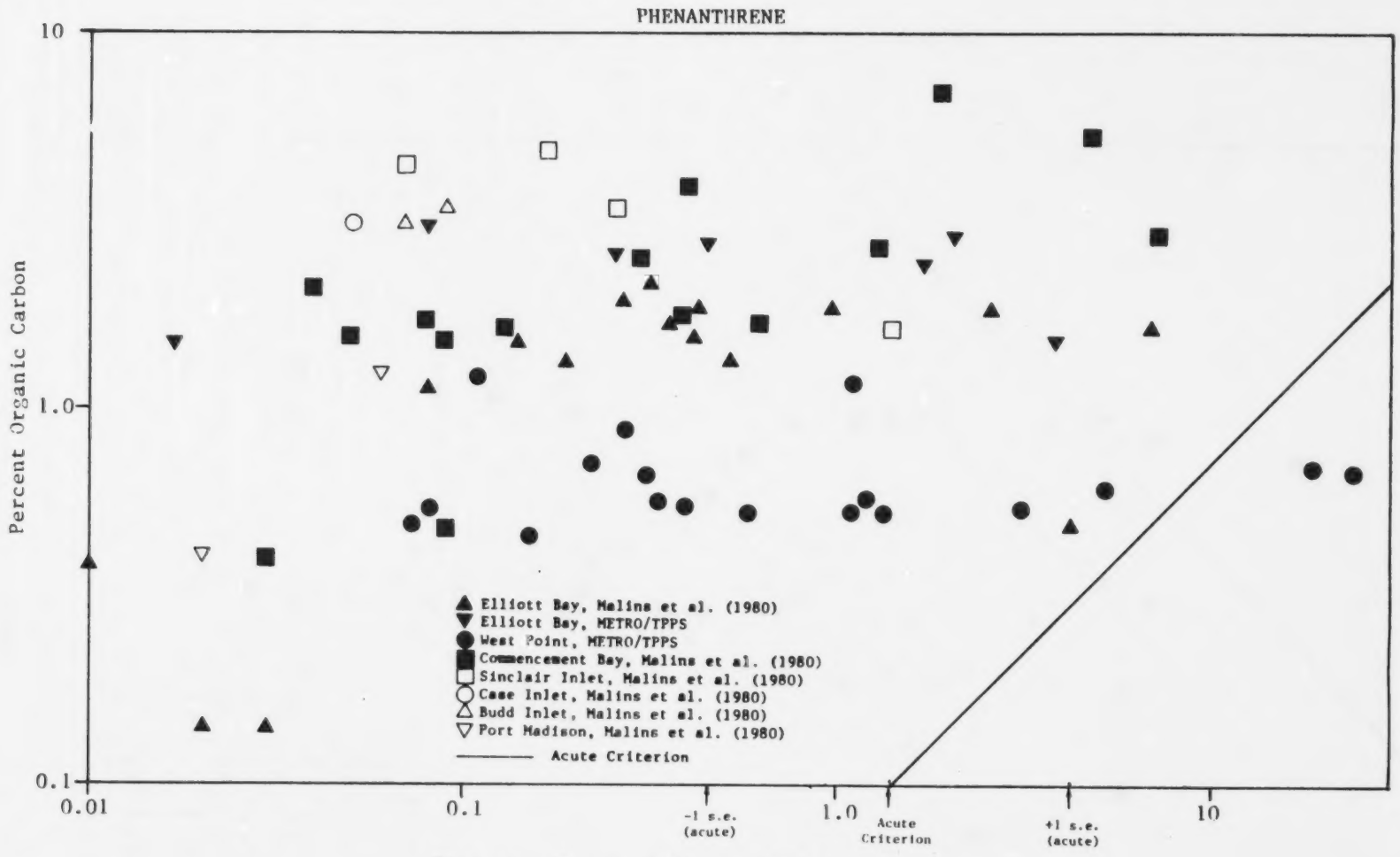

Figure 16

OBSERVED CONCENTRATIONS OF PHENANTHRENE IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

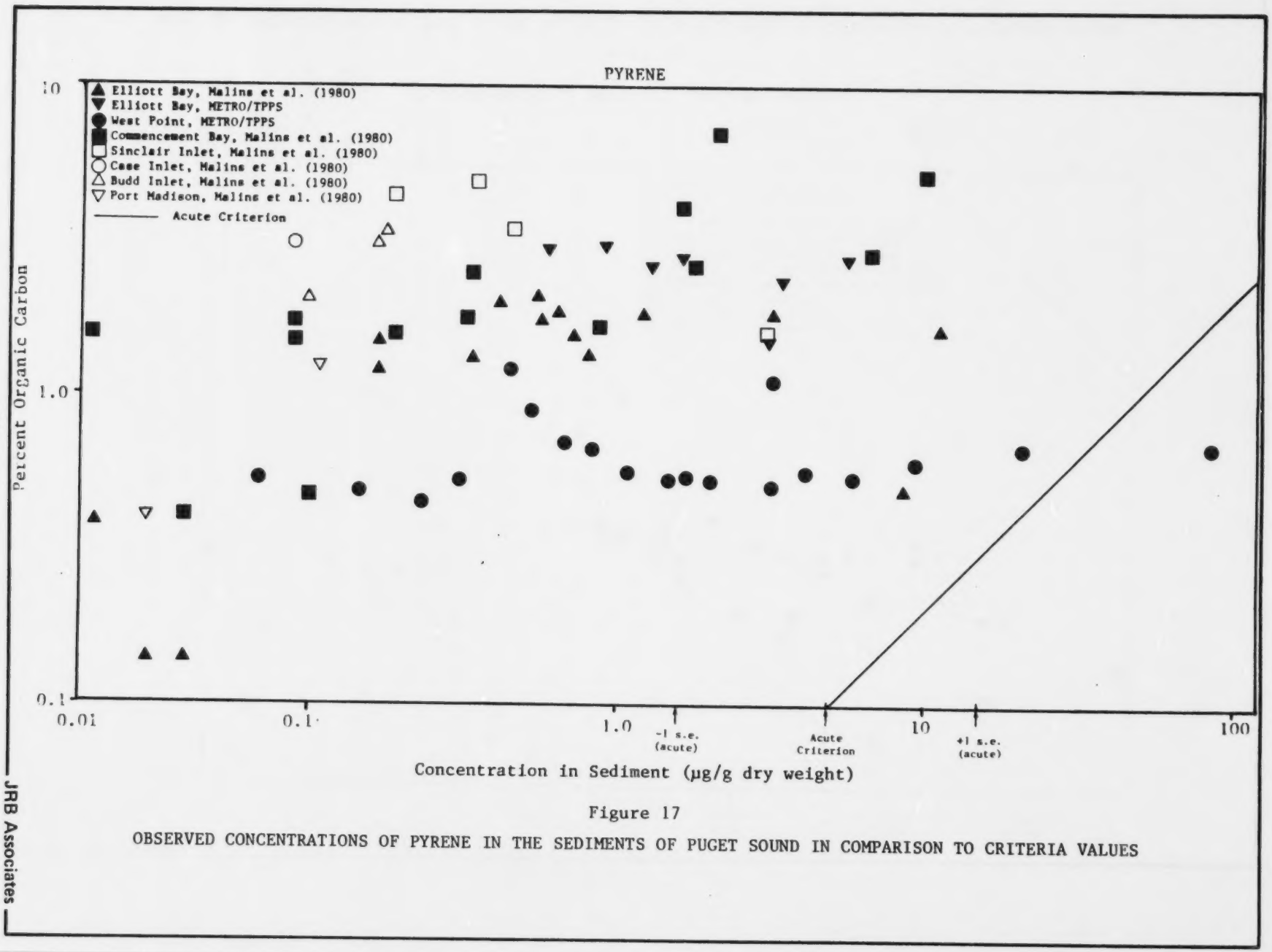

Figure 17

OBSERVED CONCENTRATIONS OF PYRENE IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

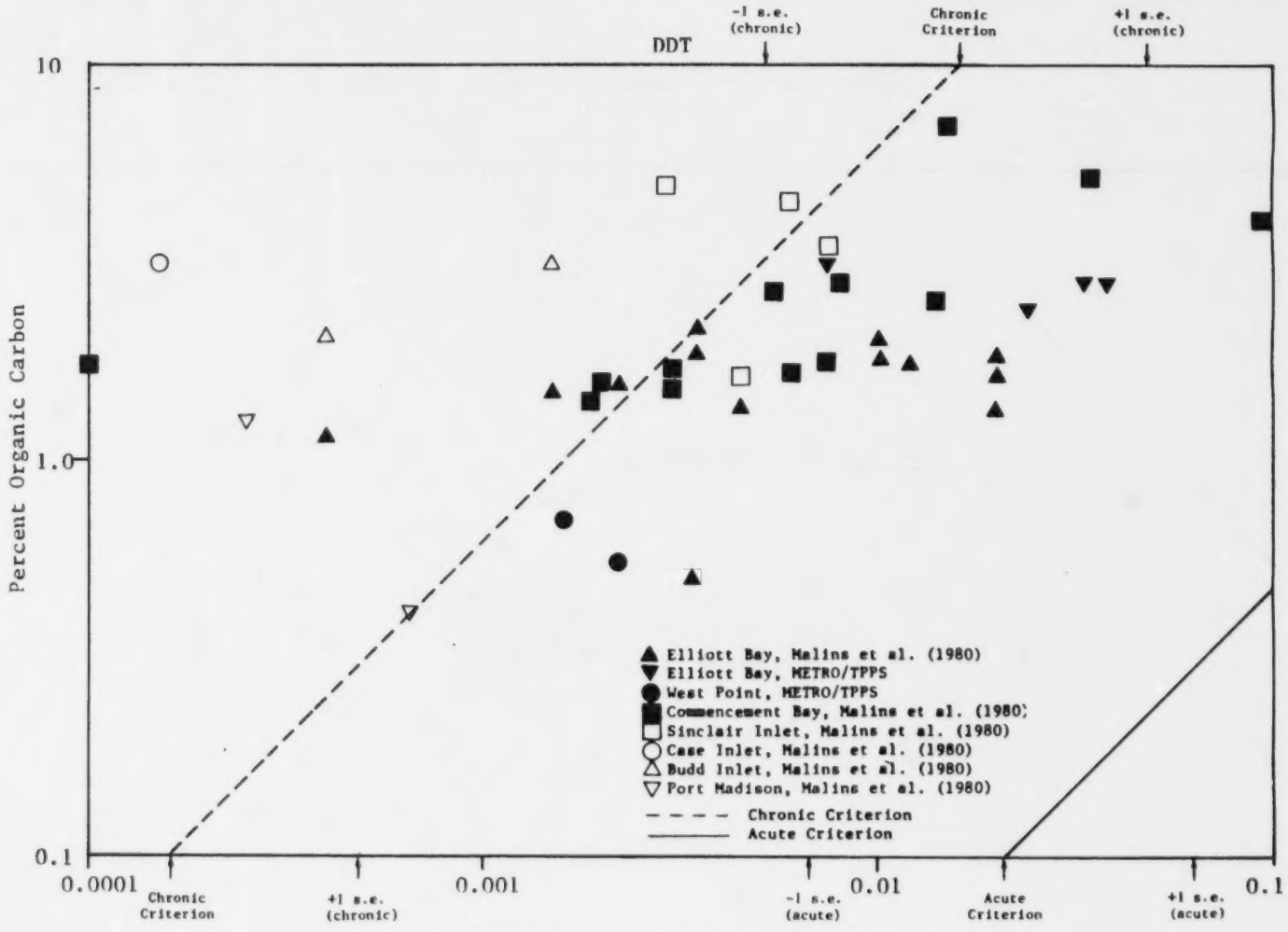

Figure 18

OBSERVED CONCENTRATIONS OF DDT IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

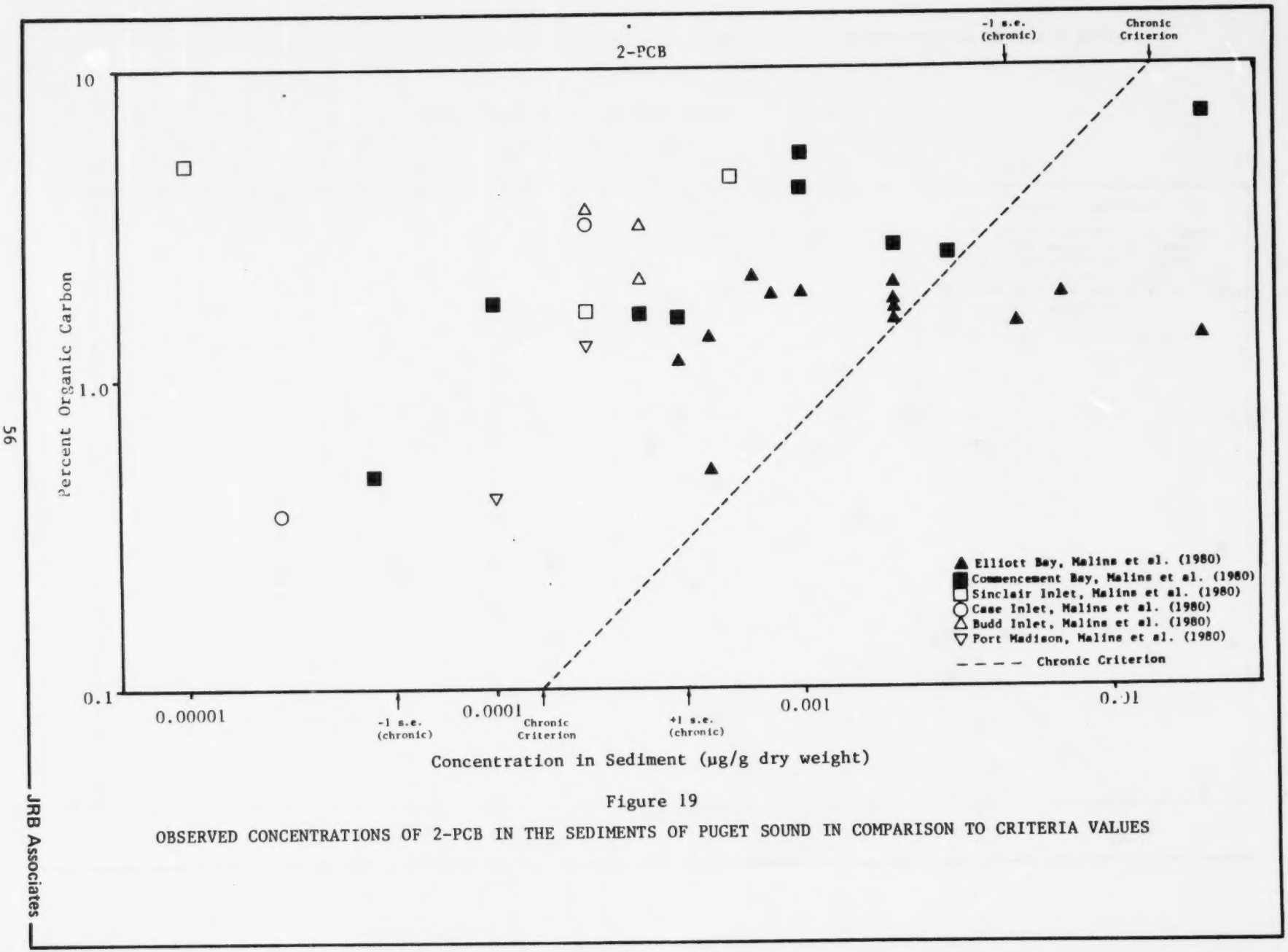

Figure 19

OBSERVED CONCENTRATIONS OF 2-PCB IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

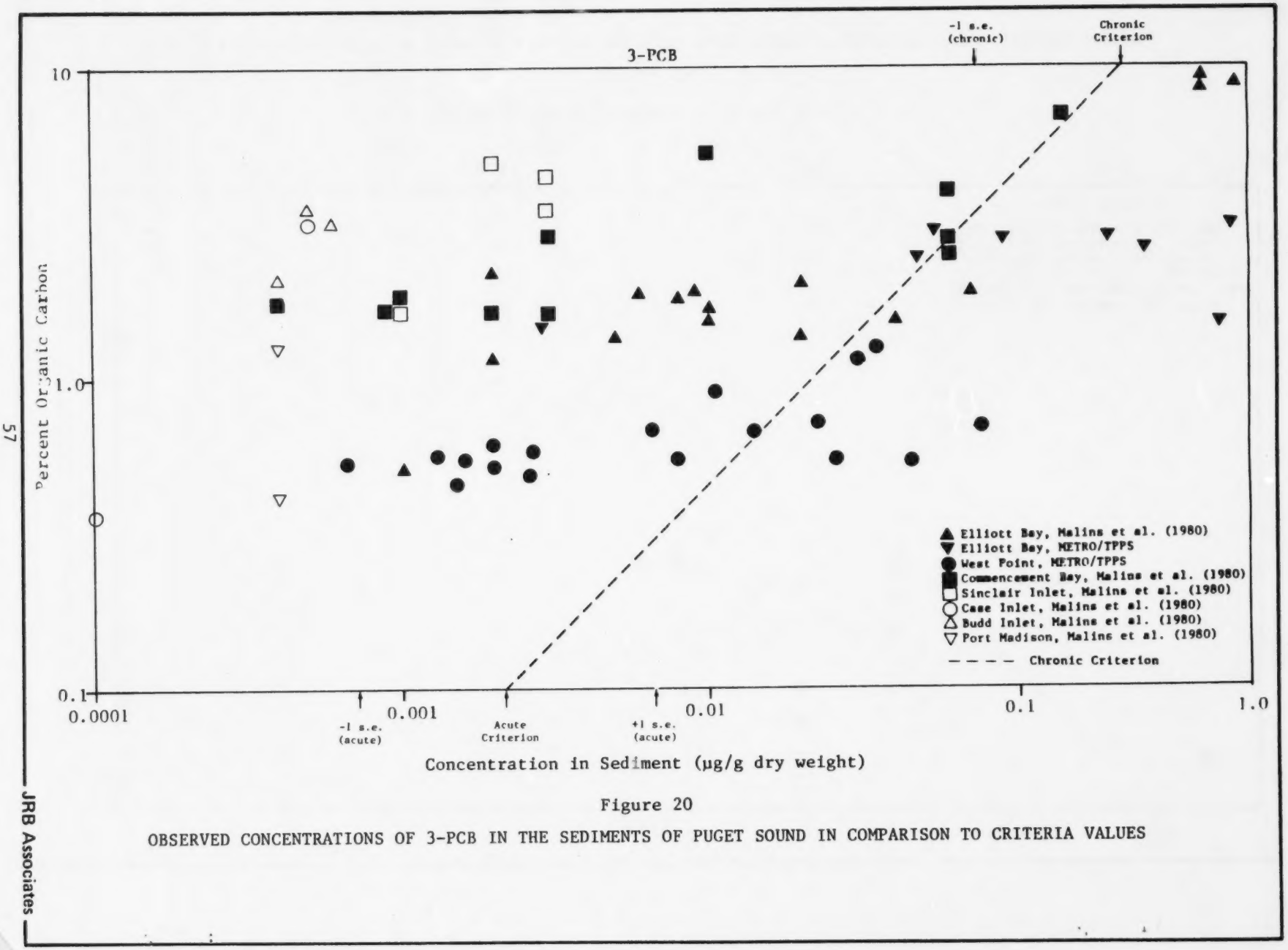

Figure 20

OBSERVED CONCENTRATIONS OF 3-PCB IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

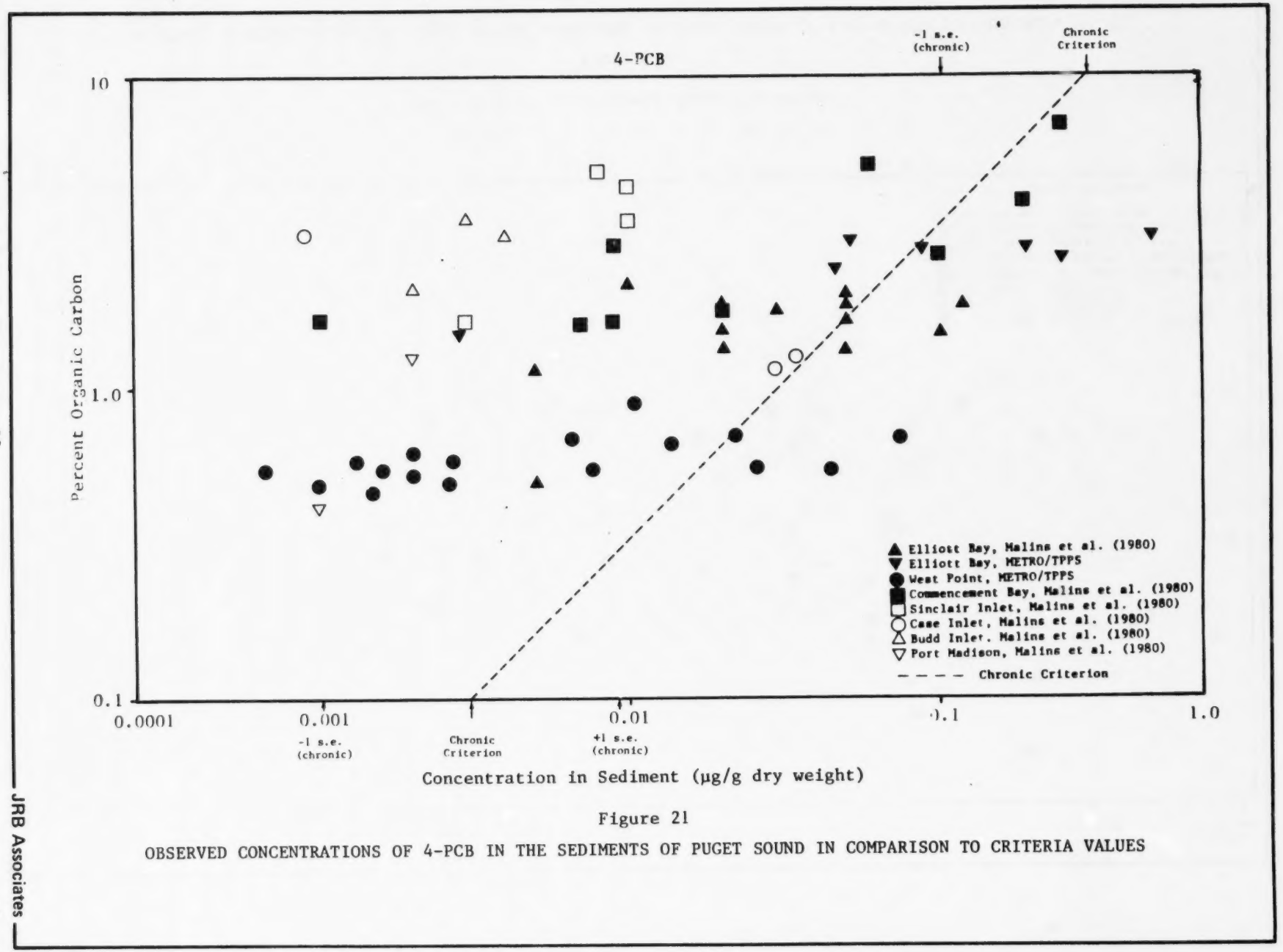

Figure 21

OBSERVED CONCENTRATIONS OF 4-PCB IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

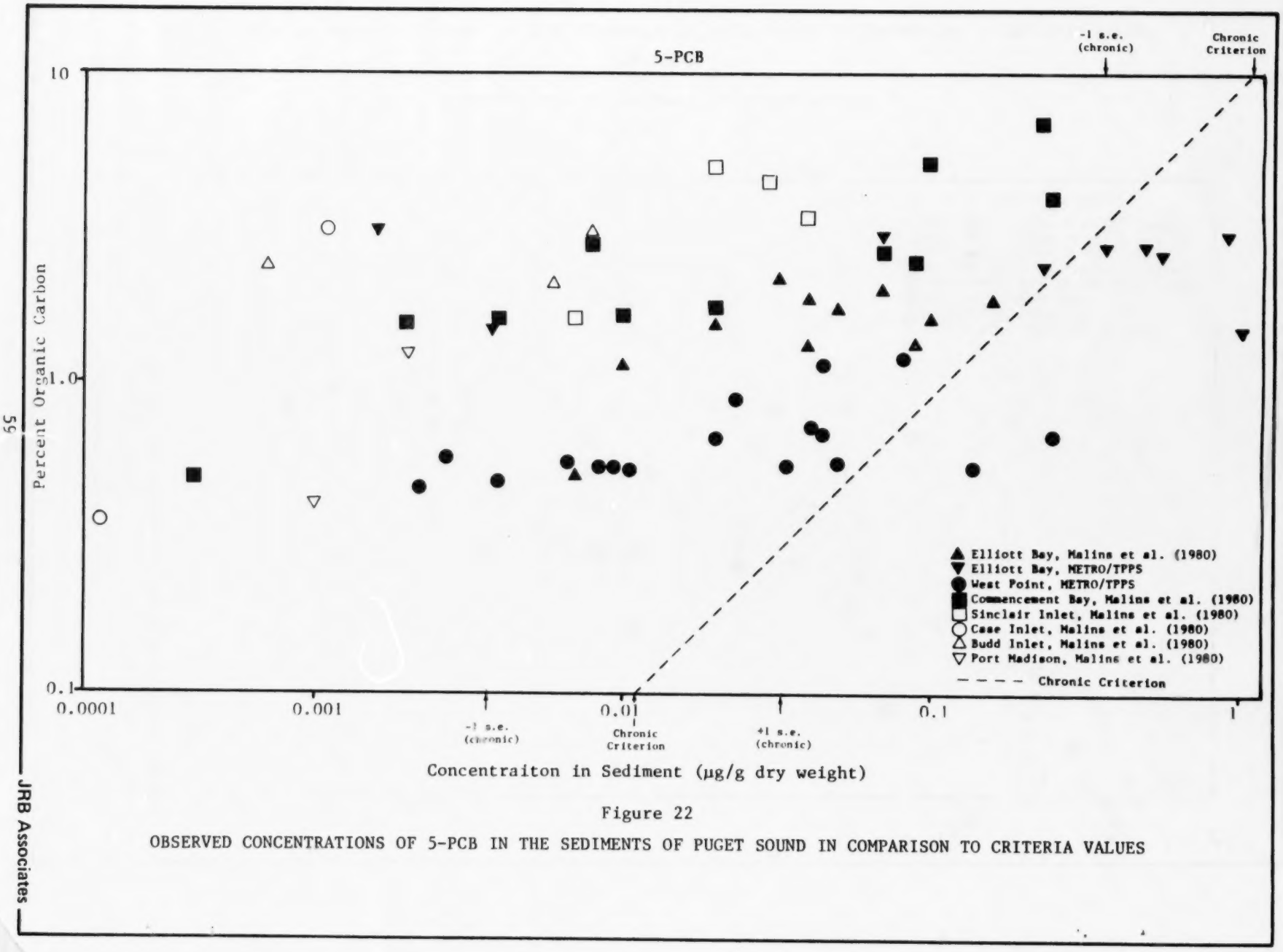

Figure 22

OBSERVED CONCENTRATIONS OF 5-PCB IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

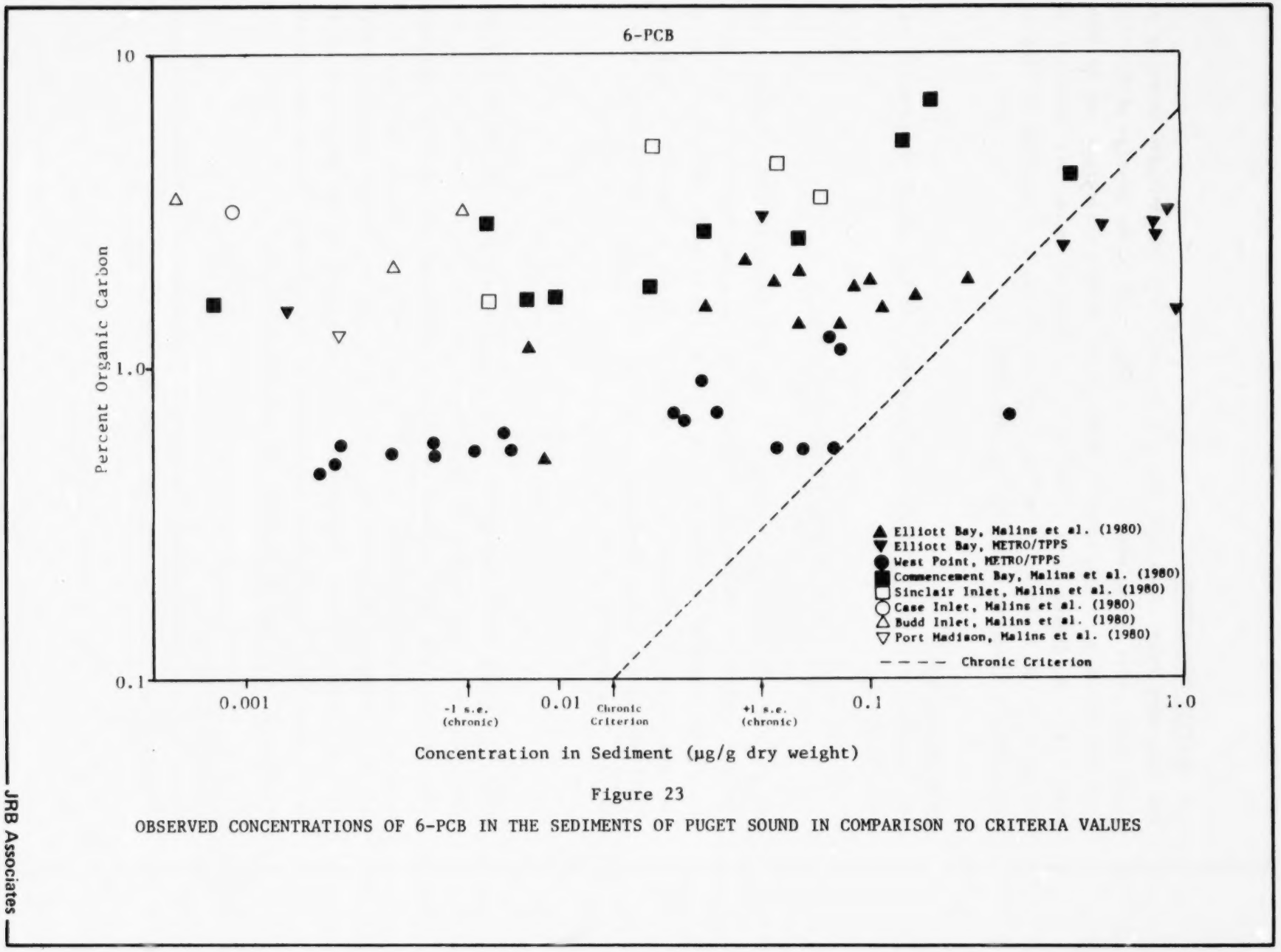

Figure 23

OBSERVED CONCENTRATIONS OF 6-PCB IN THE SEDIMENTS OF PUGET SOUND IN COMPARISON TO CRITERIA VALUES

4.4 SPATIAL COMPARISONS

The frequency with which criteria are exceeded and the relative severity of these occurrences can be used to evaluate the extent of degradation within various subregions of Puget Sound. Comparisons between subregions can be made numerically or graphically. The methods presented below are intended as examples of the tools which may be used to establish a priority listing of sites where corrective action may be necessary.

Numerical Approach

The frequency with which criteria are exceeded for individual contaminants can be defined as:

$$f_V^X = \frac{\text{\# measurements exceeding criteria}}{\text{total \# measurements}} \times 100$$

where f_V^X is defined as the frequency of criteria violation and x refers to the specific contaminant measured. Values of f_V^X were calculated for both acute and chronic sediment criteria for six trace metals as shown in Table 8. It is possible to sum the individual f_V^X values to obtain a frequency of criteria violations for a given subregion integrated for a class of priority contaminants. This quantity is defined as:

$$F_V = \frac{\Sigma_n f_V^X}{n}$$

where F_V is the class integrated frequency of criteria violation in a given region and n is the number of contaminants in the class. Values of F_V are illustrated in the last columns of Table 9. Although the sampling frequency among the subregions is quite variable it is clear that Elliott Bay, Commencement Bay, Sinclair Inlet and the area around the West Point Outfall exhibit the highest frequency of violations. This, of course, is not surprising since these areas have historically been known to receive high contaminant inputs originating from land based point and nonpoint sources.

Graphical Approach

Excess factors, representing the percent enrichment of a contaminant above criteria, can be calculated at each sampling site as:

Table 9

FREQUENCY OF CRITERIA VIOLATIONS (f_V^X) FOR SIX TRACE METALS IN SEVERAL SUBREGIONS OF PUGET SOUND

(Numbers in parentheses equal the number of stations which exceed criteria/total number of stations tested)

	As		Cd		Cu		Pb		Hg		Zn		F_V [a]	
Subregion	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
Elliott Bay	5.5 (2/36)	25 (9/36)	0 (0/36)	0 (0/36)	25 (13/53)	42 (22/53)	0 (0/53)	74 (39/53)	59 (31/53)	100 (53/53)	4 (2/53)	13 (7/53)	22 (46/212)	57 (121/212)
Commencement Bay	--	--	--	--	21 (3/14)	50 (7/14)	0 (0/14)	50 (9/14)	43 (6/14)	100 (14/14)	7 (1/14)	7 (1/14)	18 (10/56)	52 (29/56)
Sinclair Inlet	--	--	--	--	0 (0/4)	50 (2/4)	0 (0/4)	25 (1/4)	100 (4/4)	100 (4/4)	0 (0/4)	0 (0/4)	25 (4/16)	44 (7/16)
Budd Inlet	--	--	--	--	0 (0/3)	0 (0/3)	0 (0/3)	0 (0/3)	0 (0/3)	100 (3/3)	0 (0/3)	0 (0/3)	0 (0/12)	25 (3/12)
Case Inlet	--	--	--	--	0 (0/2)	0 (0/2)	0 (0/2)	0 (0/2)	0 (0/2)	100 (2/2)	0 (0/2)	0 (0/2)	0 (0/8)	25 (2/8)
Port Madison	--	--	--	--	0 (0/2)	0 (0/2)	0 (0/2)	0 (0/2)	0 (0/2)	100 (2/2)	0 (0/2)	0 (0/2)	0 (0/8)	25 (2/8)
West Pt. Outfall Region	10 (3/31)	36 (11/31)	0 (0/31)	0 (0/31)	3 (1/31)	16 (5/31)	0 (0/31)	21 (9/31)	52 (16/31)	100 (31/31)	3 (1/31)	16 (5/31)	15 (18/124)	40 (50/124)
Total	7 (5/67)	30 (20/67)	0 (0/67)	0 (0/67)	16 (17/109)	33 (36/109)	0 (0/109)	51 (56/109)	52 (57/109)	100 (109/109)	4 (4/109)	11 (13/109)		

[a] Excludes As and Cd.

$$EF = \frac{C^X_{S/ACT/OC} - C^X_{S/CR/OC}}{C^X_{S/CR/OC}}$$

where $C^X_{S/ACT/OC}$ equals the actual measured contaminant concentration normalized to organic carbon content. Computation of excess factors allows for site specificity and definition of areas where remedial and/or control-enforcement action may be necessary. It is possible to obtain this site specificity by a spatial representation of excess factors. In this manner, a gradient in the degree of violation may be established which could lead to specific source control action. A typical example of this method is depicted in Figure 24. It is apparent that chronic criteria for Cu are exceeded within the immediate proximity of the city's waterfront, the industrialized area around Harbor Island and a very short radius from shore at the Denny Way CSO site. This representation points to the severity of contamination being highly localized and therefore amenable to remedial action. Similar plots could be constructed from the other contaminants to improve site specificity of criteria violations.

4.5 CORRELATIONS WITH OTHER SEDIMENT CRITERIA

The Phase I report discussed the history of sediment criteria development and presented a variety of proposed criteria, many of which had been developed for the Great Lakes. The sediment contaminant concentrations permitted by these earlier criteria were established in a rather subjective manner but were generally based upon correlations of sediment contaminant burden with observations of adverse biological impact. It should also be pointed out here that the effect of the environmental variables discussed in Section 2.4 was not considered in the development of these criteria.

A comparison of these earlier limits with the values proposed in this report are presented in Table 10. The criteria from the literature represent the range of concentrations encompassed by the EPA-Region V, EPA Region VI and Ontario Ministry of the Environment guidelines as reported in the Phase I report. The criteria derived by the equilibrium approach are calculated assuming a 2% organic carbon content. This value is intermediate in the range of organic content typical of sediments and is representative of sediments with 50% sand and 50% silt and clay (Figure 8).

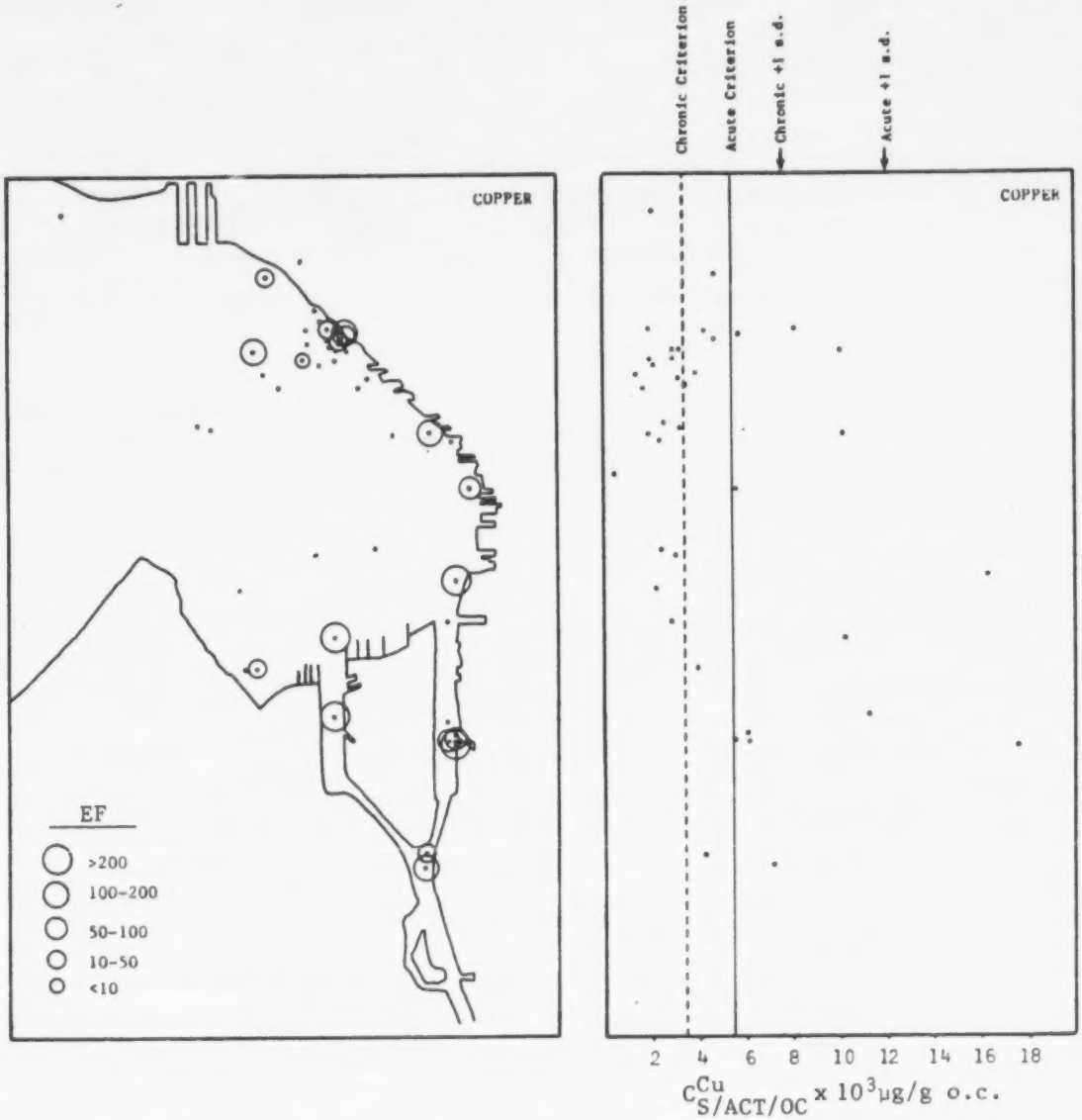

Figure 24

SPATIAL REPRESENTATION OF EXCESS FACTORS (EF) FOR CHRONIC CRITERIA COMPUTED FOR Cu AND CORRESPONDING SEDIMENT CONCENTRATIONS MEASURED AT SPECIFIC SITES IN ELLIOTT BAY
Data from Metro/TPPS (Pavlou et al., 1983), and NOAA/NMFS (Malins et al., 1980)

Table 10

COMPARISON OF SEDIMENT CRITERIA FOR GREAT LAKES SEDIMENTS TAKEN FROM THE LITERATURE AND CRITERIA ESTABLISHED BY THE SEDIMENT-WATER EQUILIBRIUM APPROACH

(concentrations given in mg/kg dry weight)

Contaminant	Sediment Criteria From the Literature	Sediment Criteria Derived by Partitioning Approach[a]
As	3-8	16
Cd	1-6	15
Cu	25-50	68
Pb	40-50	66
Hg	0.3-1	0.006
Zn	75-100	380
PCB	0.05-10	0.06[b]

[a] Based on a sediment containing 2% organic carbon.

[b] Based on an average criterion from 2-6 chlorinated biphenyls.

The criteria derived by the equilibrium approach are in remarkably close agreement with the criteria from the literature developed for Great Lakes sediments. With the exception of Hg, all criteria developed by the partitioning approach are within one order of magnitude of the literature criteria and the difference is generally much less. The fact that the proposed Hg criterion is far below the literature value suggests that our estimate may be too strict as discussed in Section 4.3. Though the proposed PCB criterion agrees well with the literature values, it should be noted that this value represents the mean criterion for 2-6 chlorinated biphenyls. The appropriate criterion can best be determined only after consideration of the relative proportions of all PCB isomers.

5.0 RECOMMENDATIONS

In performing this study a number of immediate information and research needs were identified to validate some of the inherent assumptions and improve the utility of the equilibrium partitioning approach in the development of sediment criteria. The recommendations below are separated into three categories: short-term technical needs, long-term technical needs and management needs. Within each technical category, the needs are presented in approximate order of priority taking into consideration both their contributions to validation of the partitioning approach and their development costs/time. Those recommendations ranked highly are of immediate need for application of the proposed criteria and/or can be accomplished with a relatively low level of effort.

5.1 SHORT-TERM TECHNICAL NEEDS

The following technical needs are those which could potentially be accomplished in a relatively short time frame (less than one year). The needs identified below are recommended primarily to strengthen the equilibrium partitioning approach in two general areas: 1) verify the sediment-water partitioning coefficients developed; and 2) provide additional assurance that the criteria developed are biologically meaningful and adequate to protect marine life. If the short-term technical needs identified are pursued, and the criteria refined in light of new information developed, it should be possible for environmental managers to rely on the numerical values as guidelines in assessing the extent of contamination of marine sediments and to use the values as a tool in decision making.

- Ongoing studies funded by various federal and/or regional agencies should be examined to determine flexibility for sampling contaminant and ancillary sediment parameters to enhance application of the sediment criteria and/or refine the preliminary numerical values derived by this approach. Interagency coordination during field surveys is recommended to attain cost effectiveness. EPA is currently directing an effort to achieve these objectives.

- For sites where violations are predicted by the equilibrium partitioning approach it is necessary to relate the occurrence of violations to the occurrence of biological effects on a site-specific basis. The occurrence of criteria violations should be related to indication of localized biological impact such as sediment bioassays or benthic community structure.

- The partition coefficients calculated in this study were based primarily on empirical relationships. To determine whether these values are applicable in Puget Sound, field studies should be performed to verify the predicted K_{OC} values. These investigations should include measurements of contaminants in both the interstitial water and sediments together with ancillary variables at selected sites spanning a range of contaminant levels. An effort should be made to review existing techniques in sampling interstitial water and if necessary develop the appropriate methodology for obtaining large quantities of water at the sediment water interface and bioturbation layer.

- To test the sensitivity of criteria developed by the equilibrium partitioning approach, it is recommended that sediment bioassays be performed to determine if sediment criteria are indeed below concentrations causing adverse biological effects. These bioassay experiments should employ appropriate sensitive marine species of common occurrence in the Puget Sound environment.

- It is well established that the organic content of the sediments is a dominant factor in controlling the magnitude of the partition coefficient and hence the value of the derived criteria. The development of a relationship between organic content and sediment texture in this study was limited only to one data base (Malins et al., 1980). Since 1980, additional sediment surveys have been performed by various investigators in Puget Sound. It is therefore recommended that all available data on organic carbon/sediment texture measurements be compiled and coherent plots be generated. The existence of subregional variability should also be examined to allow proper normalization of the contaminant residue measurements.

5.2 LONG-TERM TECHNICAL NEEDS

The technical needs identified below are important in the ultimate establishment of sediment criteria but would require a long-term development effort (greater than one year). Several of the needs represent research efforts needed to expand the current state of knowledge on the transfer of contaminants between sediment, water and biota. In this regard they are important not only in development of the equilibrium partitioning approach but in providing the technical basis in support of any sediment criteria eventually adopted. It is recommended that the needs identified below be pursued prior to adoption of legally defensible criteria for regulatory application.

- The bioavailability of contaminants at the sediment-water interface has been identified as a critical factor in deriving realistic sediment criteria using the equilibrium partitioning approach. An effort should be made to determine the factors effecting bioavailability of both trace metal and synthetic organic chemicals of concern in Puget Sound. These studies should include efforts to evaluate the importance of ingestion of particulate-bound contaminants in determining the ultimate contaminant body burden of deposit feeders. There is a need to examine the assumption made that ingestion of contaminated particles will not increase the body burden above that which is attained via the interstitial water.

- As pointed out in the report, the physical/chemical conditions at the sediment-water interface appear to control the chemical form of trace metals and hence their bioavailability. It is therefore recommended that experiments be performed to determine the sediment-water partitioning of trace metals as influenced by environmental conditions (organic carbon, pH, redox, DOM, temperature, salinity). These studies may include: (1) a review of pertinent literature; (2) field measurements; and (3) controlled experiments with natural sediments.

- One of the limitations in establishing sediment criteria in using the equilibrium partitioning approach is the lack of water quality criteria (chronic and acute) for most of the contaminants encountered in Puget Sound. An immediate need is therefore the update of the water quality criteria list to include acute and chronic values for all contaminants of concern measured in

Puget Sound. Though establishment of criteria for a wide diversity of contaminants would involve a major, long-term effort, it may be possible to identify a few select contaminants of greatest concern and derive criteria for these on a short-term basis.

5.3 MANAGEMENT NEEDS

- The historical and ongoing generation of sediment quality related information comprises a substantial bank of numerical values that must be properly handled, processed and documented prior to use in the criteria development program. To facilitate the use of this voluminous information a computerized data management plan must be developed. This system must be flexible and should be updated as more information becomes available. It is recommended that EPA assumes the role of a regional data base coordinator and "clearing house" and take the necessary steps to develop a regional data base management plan for sediment quality information for timely implementation. Coordination with other agencies within the region (e.g., NOAA, Washington State Department of Ecology, Army Corps of Engineers) should be encouraged since these organizations are both users and generators of information and historically have developed project specific data bases for water quality parameters and contaminants.

- The single most important need is for management agencies to continue to encourage and support development of scientifically sound, legally defensible and nationally adoptable sediment criteria. Several steps should be taken to meet this need: (1) continued support of research in the areas of contaminant transport, fate and effects as they pertain to sediment criteria; (2) development of protocols for application of criteria; (3) encourage comparison of criteria developed by alternate approaches; and (4) provide a forum for communication between scientists and agencies involved in development of sediment criteria.

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APPENDIX A

SEDIMENT CONTAMINANT CONCENTRATIONS FROM MALINS ET AL., 1980

Table A-1

TOTAL ORGANIC CARBON AND GRAIN SIZE ANALYSES OF SEDIMENTS FROM CENTRAL PUGET SOUND
(From Malins et al., 1980, Appendix Table D-7

Location Description	Station Number	Grain Size (% by weight) >-2	-2 to 0	0 to +4	+2 to +4	+4 to +8	> +8	Mean Grain Size ϕ	Sand/Mud Ratio	% Organic Carbon
Sinclair Inlet:										
Southwest end	08004		0.48	0.47	0.84	65.03	33.20	---	0.02	4.42
Drydock area	08005		0.21	0.41	2.75	46.80	49.84	---	0.03	3.44
Point Turner, southwest side	08006		0.73	7.55	9.14	46.49	36.11	7.10	0.21	4.90
Point Herron, south side	08007		0.03	2.51	53.69	20.95	22.82	5.24	1.28	1.61
Port Madison:										
Midway from Pt. Monroe to Pt. Jefferson	08106		1.44	9.83	34.23	35.56	18.93	5.12	0.83	1.26
Indianola, southwest	08107		0.06	21.26	57.33	15.12	6.21	2.95	3.68	0.41
Commencement Bay:										
Hylebos Waterway, lower turning basin	09027		0.03	0.42	2.60	77.54	19.41	6.88	0.03	4.00
" " , E. 11th St. Bridge	09028		1.45	16.06	19.21	52.84	10.44	4.76	0.58	2.82
Blair Waterway	09029		0.25	16.08	19.27	46.85	18.14	5.13	0.55	1.64
Sitcum Waterway	09030			1.34	14.88	64.15	19.64	6.08	0.19	1.78
City Waterway	09031			1.41	6.32	66.57	25.70	6.71	0.08	5.17
Puyallup disposal site	09032		0.01	0.67	42.99	49.80	6.54	4.28	0.78	1.56
Between Hylebos and Blair	09033		0.10	3.48	9.98	66.99	19.45	5.99	0.16	1.51
Brown's Point, south side	09034		0.23	2.05	12.08	61.97	23.67	6.15	0.17	2.49
Creek at sewage plant	09035	0.56	3.84	52.54	36.14	2.98	3.95	1.85	13.47	0.40
Tacoma Yacht Club	09036	1.92	7.31	40.03	42.07	3.53	5.15	1.89	10.54	1.72
Brown's Point	09037		6.65	56.81	22.49	7.64	6.41	1.86	6.12	0.48
Hylebos Waterway, outside, to NW	09038			0.22	2.20	70.07	27.51	6.69	0.02	2.64
Old Tacoma	09039		0.37	10.37	21.01	44.34	23.92	5.66	0.47	6.98
Blair Waterway, turning basin	09040		0.02	3.22	17.16	52.48	27.11	6.54	0.26	1.60

Table A-1
(cont'd)

Location Description	Station Number	Grain Size (% by weight) >-2	-2 to 0	0 to +4	+2 to +4	+4 to +8	< +8	Mean Grain Size ϕ	Sand/Mud Ratio	% Organic Carbon
Elliott Bay:										
Magnolia Bluff	10014		0.54	25.18	59.96	6.95	7.38	2.63	5.98	1.13
Pier 54	10015		0.21	3.57	6.70	58.33	31.19	7.02	0.12	1.63
Harbor Island, north end	10016	no data						no data		
Duwamish Waterway, 1st Ave Bridge	10019		0.84	20.02	11.76	52.35	15.04	4.84	0.48	1.50
West Point, north side	10023		0.01	3.59	80.07	11.11	5.22	3.26	5.12	0.50
Alki Point, south side	10028		0.09	38.07	57.52	1.28	3.02	2.23	22.23	0.39
Duwamish Waterway, near lumber mill	10031		0.03	3.13	12.29	46.45	38.09	7.11	0.18	1.33
" " , west channel	10038		0.11	2.99	15.02	40.73	41.15	7.07	0.22	1.82
" " , east channel	10039			0.58	2.82	43.76	52.83	8.52	0.04	1.70
Pier 70	10040		2.38	14.03	10.69	49.11	23.74	5.26	0.37	1.33
North of Pier 71	10041		1.33	9.72	25.36	50.08	13.51	5.03	0.57	1.83
Pier 86	10042		0.07	2.40	9.44	59.33	28.76	6.77	0.14	1.33
Corps dump site	10043		2.84	20.16	22.09	42.90	12.01	4.63	0.82	1.99
Midway from Pier 91 to Duwamish Head	10044		0.01	1.09	4.15	49.13	45.32	7.31	0.06	2.15
Duwamish Head, southeast side	10045	0.91	10.62	26.56	22.79	23.70	15.42	3.77	1.56	1.53
Pier 42	10046		1.98	24.82	60.74	10.45	2.01	2.62	7.02	0.14
Case Inlet:										
Reach Island	12062			1.26	4.67	59.00	35.07	7.39	0.06	3.10
Stretch Island	12063		0.04	24.35	65.36	5.97	4.28	2.56	8.75	0.36
Budd Inlet:										
Entrance channel, south end	12130			0.18	4.73	67.23	27.86	6.95	0.05	3.10
Priest Point	12131		0.02	10.28	35.38	29.00	25.32	5.65	0.84	2.05
Olympia Shoal	12132			0.45	0.93	47.85	50.77	---	0.01	3.41

Table A-2

CONCENTRATION OF METALS IN SEDIMENTS FROM CENTRAL PUGET SOUND IN MAY, 1979, IN µg/g DRY WEIGHT (PPM)

(From Malins, et al., 1980, Appendix Table D-2)

SOURCE OF SEDIMENT SAMPLE		ELEMENT									
		Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co
SINCLAIR INLET:	Southwest end	4·76	18811		67·4	54·0	·557		19103	8·14	14·9
	Drydock area	3·42	19650		50·0	65·2	·633		8507	7·73	13·8
	Point Turner, southwest side	2·92	17796		50·8	59·6	·585		13097	7·14	13·2
	Point Herron, south side	2·02	13070		38·5	30·2	·420		7985	5·24	9·66
PORT MADISON:	Midway from Pt. Monroe to Pt. Jefferson	1·97	13712		29·4	34·3	·490		6511	6·25	13·5
	Indianola, southwest	1·48	7309		23·6	16·3	·221		5003	3·08	5·71
COMMENCEMENT BAY:	Hylebos Waterway, lower turning basin	2·93	>20000		99·6	51·2	·703		12340	9·61	20·5
	Hylebos Waterway, E. 11th St. bridge	2·35	13060		81·4	38·8	·546	90	>20000	6·60	11·9
	Blair Waterway, E. 11th St. bridge	2·14	12857		23·4	25·6	·481		7279	5·45	8·46
	Sitcum Waterway	10·8	12104	472	16·8	34·8	·453		7022	16·2	47·9
	City Waterway	5·02	16471		40·9	79·3	·549		8412	9·09	11·8
	Puyallup disposal site	1·90	12027		17·5	34·9	·484		6209	5·20	10·6
	Between Hylebos & Blair	2·20	15027		20·2	31·8	·530		8044	5·60	12·6
	Brown's Point, south side	2·37	15671		23·9	35·1	·592		7668	5·99	15·6
	Creek at sewage plant	1·94	8503		14·3	17·4	·327		4915	4·20	12·6
	Tacoma Yacht Club	2·22	9399		25·0	24·4	·426		6144	5·80	20·0
	Brown's Point	1·95	9178		28·8	16·9	·407		4293	4·72	14·1
	Hylebos Waterway, outside, to NW	2·52	16666		30·4	36·5	·613		8467	6·06	15·5
	Old Tacoma	2·46	13009		36·5	58·1	·475		7019	5·57	14·3
	Blair Waterway, turning basin	2·18	14110		20·0	32·7	·544		7741	6·02	18·8
ELLIOTT BAY:	Magnolia Bluff	1·31	9953		26·1	25·8	·494		5063	4·46	8·75
	Pier 54	3·92	>20000		36·6	115	·866		7169	8·58	17·6
	Harbor Island, north end	1·89	14586		18·8	103	·574		6590	5·78	9·45
	Duwamish Waterway, 14th Ave. bridge	2·07	>20000		24·5	74·6	·878		6607	8·29	16·5
	West Point, north side	1·45	10114		15·8	131	·377		5229	4·71	6·86
	Alki Point, south side	1·25	7829		16·6	16·0	·276		4261	3·77	5·33
	Duwamish Waterway, near lumber mill	2·99	>20000	95	28·3	119	·995		8986	11·9	17·3
	Duwamish Waterway, west channel	2·56	>20000	84	25·4	283	·963		9654	11·3	13·5
	Duwamish Waterway, east channel	3·27	>20000	282	45·5	97·0	1·10		8886	18·3	29·7
	Pier 70	3·49	18433		23·3	76·3	·604		6223	7·03	9·88
	North of Pier 71	3·80	17423		28·5	75·7	·569		6521	6·49	10·8
	Pier 86	3·20	19891		25·9	67·6	·605		6928	7·39	14·2
	Corps dump site	2·22	17152		29·2	63·3	·556		6685	6·46	8·04
	Midway from Pier 91 to Duwamish Head	2·73	>20000		41·8	75·8	·708		7773	8·21	15·4
	Duwamish Head, southeast side	2·05	14520		23·8	73·7	·487		7109	7·39	12·9
	Pier 42	1·58	10923		15·7	28·4	·359		5733	4·57	7·64
	Pier 42	1·62	10790		12·0	27·5	·349		5807	7·52	10·2
CASE INLET:	Reach Island	2·26	18280		55·8	32·1	·588		8563	7·58	18·6
	Stretch Island	1·83	6430		15·6	11·7	·160		4643	3·16	8·60
BUDD INLET:	Entrance channel, south end	3·67	>20000	140	39·9	31·1	·759		8934	11·2	25·1
	Priest Point	2·66	17415		34·4	20·1	·433		8575	8·19	17·8
	Olympia Shoal	2·97	>20000	57	48·5	29·2	·684	81	7635	9·53	25·8

Table A-2
(cont'd)

SOURCE OF SEDIMENT SAMPLE		ELEMENT								
		Cr	Cu	Fe	Ga	Ge	Hg	K	Li	Mg	Mn
SINCLAIR INLET:	Southwest end	71·5	151	31817			1·06	190	20·9	10500	301
	Drydock area	65·2	184	32320			1·02	193	20·4	10543	352
	Point Turner, southwest side	57·3	132	30289			1·15	181	19·2	9437	308
	Point Herron, south side	39·4	46·8	22646			·315	128	13·4	6895	334
PORT MADISON:	Midway from Pt. Monroe to Pt. Jefferson	45·6	25·8	28968			·113	136	15·7	8676	345
	Indianola, southwest	22·8	10·4	12687			·042	58·4	7·42	4220	204
COMMENCEMENT BAY:	Hylebos Waterway, lower turning basin	47·6	259	39405			·790	149	15·5	11301	259
	Hylebos Waterway, E. 11th St. bridge	33·5	84·8	23507			·428	87·7	9·91	12961	202
	Blair Waterway,	27·9	59·6	25138			·132	88·1	9·72	5172	166
	Sitcum Waterway	58·7	1602	43354			·492	85·1	8·96	4904	194
	City Waterway	46·5	178	27176			1·03	125	13·4	7381	190
	Puyallup disposal site	25·5	33·7	22625			·065	71·0	7·53	4259	141
	Between Hylebos & Blair	26·9	50·6	25445			·106	98·1	11·0	5639	186
	Brown's Point, south side	28·5	64·8	26758			·173	105	11·5	6405	217
	Creek at sewage plant	31·4	43·0	18233			·100	60·1	8·83	5245	320
	Tacoma Yacht Club	36·3	110	26063			·255	88·6	8·98	5675	877
	Brown's Point	25·6	22·7	22530			·063	141	7·68	4251	213
	Hylebos Waterway, outside, to NW	29·1	77·7	26558			·197	125	12·5	7290	173
	Old Tacoma	28·7	126	22752			·336	98·2	10·7	5997	244
	Blair Waterway, turning basin	29·5	69·9	29914			·157	102	10·6	6110	143
ELLIOTT BAY:	Magnolia Bluff	27·5	23·9	19055			·095	102	8·56	4963	315
	Pier 54	54·4	91·2	33076			1·16	179	19·3	9561	391
	Harbor Island, north end	31·3	90·2	24636			1·38	116	11·9	5435	268
	Duwamish Waterway, 14th Ave. bridge	35·5	54·5	34037			·250	167	15·4	7639	285
	West Point, north side	35·6	18·9	19052			·104	76·2	9·99	7090	243
	Alki Point, south side	27·5	10·2	15856			·031	69·4	8·90	5582	352
	Duwamish Waterway, near lumber mill	44·8	131	45569		119	·383	222	21·4	9001	414
	Duwamish Waterway, west channel	63·9	206	45659		88	·798	226	21·6	9785	430
	Duwamish Waterway, east channel	49·2	109	>50000	86	188	·350	269	25·4	11363	567
	Pier 70	54·0	135	32640			·632	148	16·3	8891	355
	North of Pier 71	53·6	58·8	29460			1·07	154	16·5	9304	323
	Pier 86	54·0	63·7	34013			·355	166	17·4	9735	478
	Corps dump site	38·7	59·6	30267			·423	139	14·0	7163	382
	Midway from Pier 91 to Duwamish Head	51·2	69·1	37278		44	·449	210	21·9	10652	471
	Duwamish Head, southeast side	69·8	60·7	35247			·153	108	13·4	8095	591
	Pier 42	40·4	23·2	20926			·026	63·6	7·46	6830	295
	Pier 42	41·1	22·5	22214			·026	62·6	7·66	6929	316
CASE INLET:	Reach Island	52·7	45·0	28109		43	·118	167	20·5	9962	285
	Stretch Island	20·9	10·2	11120			·024	44·3	7·22	3533	102
BUDD INLET:	Entrance channel, south end	49·4	81·1	36217		101	·329	167	26·8	10407	230
	Priest Point	34·6	36·6	24748		46	·125	105	16·4	7078	154
	Olympia Shoal	50·1	70·3	34800		89	·283	164	24·7	10248	229

Table A-2
(cont'd)

SOURCE OF SEDIMENT SAMPLE		ELEMENT									
		Mo	Na	Ni	P	Pb	Sb	Sc	Se	Si	Sn
SINCLAIR INLET:	Southwest end	13·5	>20000	51·4	1227	97·6	43·5	7·13	30	137	37
	Drydock area	14·4	>20000	52·9	985	136	52·0	7·48	30	150	35
	Point Turner, southwest side	12·9	>20000	48·1	893	125	48·6	6·81	27	169	40
	Point Herron, south side	8·02	11728	35·5	697	44·2	31·1	5·02		133	29
PORT MADISON:	Midway from Pt. Monroe to Pt. Jefferson	8·47	12521	42·0	705	20·1	32·4	5·92	22	144	20
	Indianola, southwest		4458	21·5	405	10·3	17·8	3·00		140	12
COMMENCEMENT BAY:	Hylebos Waterway, lower turning basin	17·2	>20000	64·4	1098	154	64·1	6·35	34	189	36
	Hylebos Waterway, E. 11th St. bridge	11·2	12846	41·9	813	111	43·2	4·06	27	149	32
	Blair Waterway, E. 11th St. bridge	8·44	9770	21·1	812	42·5	35·1	4·17		137	22
	Sitcum Waterway	114	10398	36·1	739	793	338	3·77	23	121	65
	City Waterway	13·1	17059	33·3	1017	269	44·0	5·26	23	146	31
	Puyallup disposal site	8·19	7972	18·7	737	14·0	29·2	3·88		207	19
	Between Hylebos & Blair	9·04	10966	22·8	858	27·6	38·7	4·84		135	19
	Brown's Point, south side	10·3	13548	24·0	917	39·9	39·4	5·15	23	137	20
	Creek at sewage plant	7·24	3860	29·4	428	28·8	27·4	3·55		133	15
	Tacoma Yacht Club	10·4	4198	38·5	557	65·1	52·6	3·88		117	20
	Brown's Point	7·23	4198	22·2	491	18·3	25·7	3·81		103	15
	Hylebos Waterway, outside, to NW	12·8	19112	24·8	940	50·1	41·5	5·42	23	121	19
	Old Tacoma	14·1	12256	25·4	800	170	36·1	4·43	22	101	70
	Blair Waterway, turning basin	12·1	14268	22·4	1474	49·0	39·2	4·53		91	18
ELLIOTT BAY:	Magnolia Bluff	6·16	5029	24·6	551	37·1	25·9	3·82		104	20
	Pier 54	13·6	16400	56·4	868	111	48·8	8·40	34	100	36
	Harbor Island, north end	7·94	9584	24·2	680	60·8	34·8	5·47		88	22
	Duwamish Waterway, 14th Ave. bridge	14·8	13084	29·6	878	40·1	48·5	9·89	40	132	30
	West Point, north side	6·24	5799	41·7	473	16·1	21·1	3·75		117	19
	Alki Point, south side		4750	34·8	394	13·0	17·0	2·95		110	14
	Duwamish Waterway, near lumber mill	29·5	15823	36·0	1174	265	73·5	13·1	80	101	52
	Duwamish Waterway, west channel	26·4	18383	38·9	1020	627	80·4	12·4	70	101	52
	Duwamish Waterway, east channel	41·3	19744	47·9	1378	160	81·8	16·1	113	200	65
	Pier 70	10·9	11705	50·4	817	88·6	41·5	7·44	28	156	32
	North of Pier 71	9·98	12377	52·9	686	74·3	39·3	6·92	25	160	31
	Pier 86	11·4	16270	57·5	879	72·8	45·4	7·72	30	150	32
	Corps dump site	10·2	12604	30·0	798	65·1	47·0	6·87	26	153	26
	Midway from Pier 91 to Duwamish Head	14·8	>20000	45·0	968	78·0	51·1	8·60	39	185	37
	Duwamish Head, southeast side	9·93	6640	55·2	649	111	34·9	5·83	23	152	29
	Pier 42	6·71	4244	46·5	371	8·18	25·7	4·28		216	15
	Pier 42	6·00	5286	49·4	398	9·37	24·8	4·32		178	20
CASE INLET:	Reach Island	13·3	>20000	47·0	947	23·9	46·0	7·22	28	117	24
	Stretch Island	5·85	4935	19·4	303	7·93	19·0	2·89		143	9·6
BUDD INLET:	Entrance channel, south end	29·7	>20000	47·6	917	60·1	68·6	9·49	74	105	38
	Priest Point	11·6	14058	34·8	670	22·6	43·7	6·16	28	123	26
	Olympia Shoal	19·7	>20000	44·7	1051	49·3	61·0	8·75	59	142	38

Table A-2
(cont'd)

SOURCE OF SEDIMENT SAMPLE		ELEMENT						
		Sr	Ti	V	W	Y	Zn	Zr
SINCLAIR INLET:	Southwest end	183	1058	64·5	21	10·1	156	7·36
	Drydock area	87·3	1117	70·4	26	10·4	238	6·36
	Point Turner, southwest side	99·6	1051	67·0	24	9·99	292	6·29
	Point Herron, south side	64·7	903	50·9	14	7·97	83·2	4·36
PORT MADISON:	Midway from Pt. Monroe to Pt. Jefferson	51·1	1060	60·1	16	8·27	61·9	5·95
	Indianola, southwest	30·4	731	30·3	7·9	4·86	26·8	4·34
COMMENCEMENT BAY:	Hylebos Waterway, lower turning basin	298	1065	80·2	29	9·73	324	12·3
	Hylebos Waterway, E. 11th St. bridge	513	942	66·7	19	7·76	134	11·6
	Blair Waterway, E. 11th St. bridge	91·8	1046	66·9	14	7·34	75·4	9·12
	Sitcum Waterway	85·6	834	59·1	51	6·44	1720	9·56
	City Waterway	109	1009	66·5	22	9·14	224	9·24
	Puyallup disposal site	81·8	1135	68·6	14	6·77	40·5	6·50
	Between Hylebos & Blair	102	1123	69·7	17	8·27	57·0	7·52
	Brown's Point, south side	104	1084	71·3	18	8·68	63·9	7·80
	Creek at sewage plant	32·9	840	43·4	11	5·32	46·5	5·52
	Tacoma Yacht Club	47·4	849	56·4	14	6·18	140	4·78
	Brown's Point	39·4	730	45·5	10	6·97	35·1	5·99
	Hylebos Waterway, outside, to NW	113	1066	71·3	19	9·16	81·8	9·33
	Old Tacoma	103	865	60·5	18	7·93	208	5·83
	Blair Waterway, turning basin	113	900	70·0	17	8·19	92·2	7·34
ELLIOTT BAY:	Magnolia Bluff	43·9	834	47·4	10	6·24	58·3	4·64
	Pier 54	105	1308	81·5	26	11·6	133	8·91
	Harbor Island, north end	73·3	1099	64·1	13	8·19	106	7·01
	Duwamish Waterway, 14th Ave. bridge	94·9	1331	84·1	30	13·8	96·2	9·33
	West Point, north side	37·4	915	45·8	9·4	5·39	44·0	4·76
	Alki Point, south side	26·5	699	34·9	8·2	4·64	30·3	3·90
	Duwamish Waterway, near lumber mill	124	1649	95·9	61	15·7	204	9·07
	Duwamish Waterway, west channel	123	1534	92·2	56	14·8	319	9·30
	Duwamish Waterway, east channel	142	1931	107	81	18·1	175	12·2
	Pier 70	68·7	1289	75·7	20	9·92	97·2	7·73
	North of Pier 71	62·3	1211	67·9	19	9·48	97·8	8·36
	Pier 86	77·8	1284	75·0	22	10·3	91·0	7·96
	Corps dump site	78·4	1203	70·8	19	9·81	127	8·29
	Midway from Pier 91 to Duwamish Head	95·5	1248	81·2	31	11·6	115	7·94
	Duwamish Head, southeast side	62·8	1119	68·8	17	7·96	110	6·94
	Pier 42	33·1	1070	52·0	11	5·99	29·7	7·89
	Pier 42	33·9	1099	56·3	11	6·34	32·1	7·29
CASE INLET:	Reach Island	86·5	1052	60·7	23	9·81	82·5	6·34
	Stretch Island	26·4	679	28·0	8·0	4·26	23·2	4·04
BUDD INLET:	Entrance channel, south end	89·9	1326	71·3	58	10·7	118	10·7
	Priest Point	70·2	1122	49·2	23	7·57	55·1	9·12
	Olympia Shoal	85·3	1233	68·9	45	10·4	101	10·5

Table A-3

CONCENTRATIONS OF TARGET ORGANIC COMPOUNDS IN SEDIMENTS FROM ELLIOTT BAY, IN ng/g DRY WEIGHT (PPB)
(From Malins et al., 1980, Appendix Table D-3)

SAMPLE NUMBER	88	64	60	31	83	86	24	37	38	32	59	87	78	73	81	58	67
STATION NUMBER	10014	10015	10016	10019	10023	10028	10031	10038	10039	10040	10041	10042	10043	10044	10045	10046	10048
I-PROPYLBENZENE	2 0	6 0	2 0	40	10	60 <	50	7 0	1 0	2 0	4 0	60	30	3 0 <	50	1 0	1 0
N-PROPYLBENZENE	80 <	6 0 <	2 0	70	10	1 0	40 <	1 0	2 0	1 0	9 0	3 0	2 0	2 0	3 0	1 0	2 0
INDAN	1 0	30	7 0	6 0 <	80	30	2 0	20	4 0	90	7 0	20	4 0	4 0	2 0	50	1 0
NAPHTHALENE	50	8 0	610	20	680	8 0	80	310	70	80	220	160	140	210	90	5 0	10
BENZOTHIOPHENE	2 0	80	8 0	90	20	10 <	90 <	2 0	3 0	4 0	7 0	6 0	4 0	5 0 <	90 <	20 <	20
2-METHYLNAPHTHALENE	20	1300	250	30	280	5 0	60	150	50	40	90	70	50	80	50	3 0	4 0
1-METHYLNAPHTHALENE	20	540	110	10	130	2 0	30	90	20	20	40	40	30	40	20	1 0	2 0
BIPHENYL	6 0	430	50	6 0	70	2 0	20	40	10	10	30	30	20	30	9 0	70	80
2,6-DIMETHYLNAPHTHALENE	20	600	110	30	210	3 0	50	80	40	20	60	60	40	60	30	1 0	2 0
ACENAPHTHALENE	4 0	190	10 <	10	270 <	10 <	50	10	1 0 <	10	20	10	5 0	10	3 0 <	10 <	10
ACENAPHTHENE	4 0	1300	210	20	150	1 0	140	350	30	20	50	40	50	30	20	2 0	4 0
FLUORENE	10	970	210	30	270	60	170	350	60	30	60	60	40	30	70	3 0	6 0
DIBENZOTHIOPHENE	1 0	340	50	5 0	690	60	80	140	80	30	80	30	70	40	150	2 0	3 0
PHENANTHRENE	80	6800	1600	140	4200	10	960	2600	370	190	400	520	270	320	410	20	30
ANTHRACENE	30	2400	1200	180	1200	3 0	290	630	160	70	230	190	70	90	580	7 0	5 0
FLUORANTHENE	130	7600	3200	160	6100	20	1700	3700	770	240	490	730	330	450	700	30	50
PYRENE	160	11000	2800	170	8500	20	1200	3200	570	340	640	810	410	540	720	30	40
BENZ(A)ANTHRACENE	80	6800	1400	100	4800	10	1100	2700	510	180	310	660	140	290	670	30	30
CHRYSENE	70	6000	900	70	3900	9 0	920	2400	450	200	360	660	130	260	610	30	30
BENZOFLUORANTHENES	130	4700	2500	110	6800	20	1360	8400	730	480	710	1300	240	570	810	30	40
BENZO(E)PYRENE	60	4000	1100	40	2800	9 0	480	1700	300	250	330	590	120	250	390	10	10
BENZO(A)PYRENE	40	2200	960	40	4000	6 0	440	1900	240	220	260	440	80	180	170	10	10
PERYLENE	60	1700	370	270	1400	8 0	270	930	150	150	170	210	130	200	70	8 0	2 0
INDENO(1,2,3-CD)PYRENE	30	2900	480	20	2400	3 0	240	870	160	120	150	280	90	130	120	8 0	10
2,3,5 TRIMETHYLNAPHTHALEN	140	1000	100	50	320	4 0	50	70	30	30	60	50	60	60	40 <	20	30
HEXACHLOROBENZENE	070	30	10	10	030	020	20	40	20	20	30	50	10	20	070 <	010 <	010
LINDANE	< 010	< 10	< 020	< 10	< 020	< 010	< 10	< 060	< 080	2 0 <	020 <	050 <	060 <	020 <	030 <	010 <	010
HEPTACHLOR	< 020	< 80	< 50	< 20	< 020	< 010	< 80	< 20	3 0	10 <	40 <	30 <	40 <	10 <	050 <	010 <	010
ALDRIN	< 020	< 10	< 040	< 020	< 020	< 010	< 20	< 10	< 30	< 020	< 020	< 040	< 080	< 030	< 10	< 010	< 010
O,P' - DDE	< 40	< 2 0	< 80	< 1 0	40	< 050	< 1 0	< 2 0	4 0	< 50	< 70	< 70	< 2 0	3 0	2 0	< 050	10
A-CHLORDANE	< 20	< 2 0	< 40	< 40	20	< 030	< 2 0	< 1 0	3 0	< 60	< 50	< 60	< 50	20	30	< 010	< 010
TRANS-NONACHLOR	< 20	< 2 0	< 40	< 40	10	< 030	< 2 0	< 1 0	2 0	< 60	< 50	< 60	< 50	20	30	< 010	< 010
P,P' - DDE	< 40	2 0	80	2 0	20	< 040	2 0	1 0	2 0	1 0	1 0 <	30	1 0	1 0	50 <	030	040
O,P' - DDD	40	40	< 2 0	< 3 0	20	< 050	< 3 0	< 4 0	2 0	1 0 <	1 0 <	1 0 <	2 0	70	4 0	< 070	040
M,P' - DDD	< 60	< 9 0	< 3 0	< 2 0	40	< 070	< 3 0	< 4 0	9 0	< 1 0	< 2 0	< 3 0	< 3 0	1 0	2 0	10 <	070
P,P' - DDD/O,P' - DDT	80	< 10	30	10	3 0	< 040	7 0	20	10	1 0	2 0	20	20	3 0	3 0	< 060	< 040
P,P' - DDT	< 40	20	10	3 0	90	< 050	7 0	10	7 0	4 0	6 0	10	< 8 0	2 0	70	< 080	060
DICHLOROBIPHENYLS	40	2 0	40	5 0	50	< 050	7 0	1 0	2 0	20	80	30	2 0	70	2 0 <	050 <	040
TRICHLOROBIPHENYLS	2 0	10	5 0	40	1 0	< 040	70	9 0	8 0	20	6 0	5 0	20	2 0	10 <	050 <	10
TETRACHLOROBIPHENYLS	5 0	50	20	100	5 0	< 10	120	50	30	50	20	20	50	10	20 <	10 <	30
PENTACHLOROBIPHENYLS	10	100	40	160	7 0	< 080	160	160	50	90	40	40	70	32	20 <	090 <	30
HEXACHLOROBIPHENYLS	8 0	140	40	110	8 0	< 080	100	210	90	80	50	60	60	30	20 <	080 <	30
HEPTACHLOROBIPHENYLS	8 0	140	50	30	30	< 060	70	190	110	50	30	30	30	30	20	060 <	20
OCTACHLOROBIPHENYLS	2 0	30	10	1 0	8 0	050	4 0	40	40	3 0	10	10	8 0	30	3 0	050	20
NONACHLOROBIPHENYLS	40	20	6 0	30	20	< 020	2 0	5 0	8 0	1 0	2 0	3 0	80	5 0	4 0	020	050
DICHLOROBENZENE	030	1 0	20	20	90	< 030	< 40	< 40	050	20	20	30	20	10	20	040	040
TRICHLOROBUTADIENE	40	8 0	70	10	40	50	20	1 0	70	3 0	1 0	2 0	1 0	6 0	1 0	040 <	070
TETRACHLOROBUTADIENE	3 0	40	8 0 <	10	2 0	2 0	60	5 0	2 0	10	5 0	7 0	5 0	30	5 0	030	040
PENTACHLOROBUTADIENE	20	4 0	1 0 <	10	080	10 <	20	60	20	1 0	1 0	1 0	1 0	3 0	40	030	030
HEXACHLOROBUTADIENE	20	1 0	40	10	40	20 <	20	60	20	60	40	70	60	3 0	30	010	010
% DRY WT	78	48	61	57	74	77	47	45	42	57	57	51	55	38	63	76	79
SAMPLE WT GRAMS	97 7	98 3	102	100	101	97 1	100	100	101	100	100	100	102	101	98 1	101	103

Table A-4

CONCENTRATIONS OF TARGET ORGANIC COMPOUNDS IN SEDIMENTS FROM COMMENCEMENT BAY, IN ng/g DRY WEIGHT (PPB)
(From Malins et al., 1980, Appendix Table D-4)

SAMPLE NUMBER	45	48	46	43	32	30	49	82	81	55	62	63	44	51
STATION NUMBER	9027	9028	9029	9030	9031	9032	9033	9034	9035	9036	9037	9038	9039	9040
1-PROPYLBENZENE	1 0	9 0	6 0	3 0	3 0	50	2 0	2 0	80	90	< 50	50	640	70
N-PROPLYLBENZENE	6 0	30	8 0	1 0	40	1 0	90	2 0	1 0 <	40	< 50	3 0	730	1 0
INDAN	< 80	9 0	6 0	3 0	80	90	50	5 0	60 <	40	< 50	6 0	3 0	3 0
NAPHTHALENE	100	2600	440	170	4000	70	80	310	30	50	80	1300	400	60
BENZOTHIOPHENE	6 0	5 0	20	9 0	230	2 0	2 0	10	60 <	60 <	80	20	50	2 0
2-METHYLNAPHTHALENE	60	880	110	40	1600	20	20	220	10	10	30	710	270	20
1-METHYLNAPHTHALENE	20	550	90	30	720	20	20	90	4 0	8 0	20	240	110	10
BIPHENYL	20	270	70	20	490	8 0	10	40	4 0	2 0	6 0	180	150	10
2,6-DIMETHYLNAPHTHALENE	40	430	130	50	820	40	40	170	6 0	10	30	540	210	30
ACENAPHTHALENE	< 70	280	30	20	310	10	20	30 <	10	3 0	6 0	110	1 0	10
ACENAPHTHENE	40	310	90	100	710	3 0	7 0	30	4 0	3 0	3 0	90	280	10
FLUORENE	40	820	80	80	810	30	20	40	2 0	4 0	3 0	190	310	7 0
DIBENZOTHIOPHENE	90	370	40	70	220	4 0	5 0	3 0	6 0	8 0	3 0	30	310	30
PHENANTHRENE	400	7300	630	390	4800	50	90	300	30	80	90	1300	1900	130
ANTHRACENE	200	670	170	100	2200	8 0	20	60	9 0	20	20	290	600	40
FLUORANTHENE	1700	6400	900	380	6100	30	110	300	40	90	90	2000	2600	230
PYRENE	1600	6700	870	320	10000	20	100	340	40	90	100	1800	2100	190
BENZ(A)ANTHRACENE	1600	3200	710	220	4700	10	60	110	20	50	40	780	2100	180
CHRYSENE	2400	3000	750	170	3800	10	60	180	20	30	40	1200	1700	260
BENZOFLUORANTHENES	2900	11000	720	200	6600	4 0	70	250	20	70	70	1800	1100	250
BENZO(E)PYRENE	1200	1900	450	120	3100	6 0	40	100	10	30	30	770	790	170
BENZO(A)PYRENE	500	1700	190	70	2600	2 0	20	60	6 0	20	10	350	340	60
PERYLENE	200	470	220	50	630	3 0	20	70	6 0	20	20	160	140	100
INDENO(1,2,3-CD)PYRENE	430	1100	180	60	1300	40	20	30	5 0	10 <	90	150	280	70
2,3,5 TRIMETHYLNAPHTHALEN	40	490	170	40	800	60	50	190	9 0	20	30	420	240	30
HEXACHLOROBENZENE	20	60	3 0	2 0	3 0	1 0	10	60	10	20	1 0	50	250	2 0
LINDANE	< 2 0	< 020	< 10	< 090	< 2 0	< 10	50	2 0	< 010	< 010	< 010	2 0	7 0	< 060
HEPTACHLOR	< 1 0	< 050	< 20	< 10	< 2 0	< 10	< 10	1 0	< 010	< 020	< 010	< 10	20	< 20
ALDRIN	< 1 0	< 060	< 20	2 0	< 2 0	< 10	1 0	70	< 030	< 040	70	4 0	< 1 0	< 090
O,P' - DDE	20	1 0	2 0	2 0	9 0	40	< 20	< 10	< 080	10	< 040	< 60	3 0	60
A-CHLORDANE	2 0	30	3 0	1 0	< 2 0	< 20	90	10	< 040	10	< 010	90	20	10
TRANS-NONACHLOR	2 0	30	50	60	4 0	< 20	80	5 0	< 040	10	050	8 0	10	10
P,P' - DDE	10	20	1 0	60	5 0	20	50	70	< 050	040	< 010	50	7 0	20
O,P' - DDD	6 0	30	40	50	3 0	< 20	< 50	< 90	< 10	< 030	< 020	< 50	90	< 20
M,P' - DDD	8 0	1 0	1 0	1 0	10	< 30	< 50	< 1 0	< 20	< 050	40	< 70	< 4 0	50
P,P' - DDD/O,P' - DDT	50	10	6 0	9 0	30	2 0	2 0	10	< 10	20	50	5 0	10	2 0
P,P' - DDT	70	3 0	3 0	3 0	20	2 0	1 0	9 0	< 20	< 050	1 0	3 0	10	2 0
DICHLOROBIPHENYLS	< 10	1 0	< 30	< 40	1 0	40	< 30	3 0	< 060	10	040	2 0	20	30
TRICHLOROBIPHENYLS	60	3 0	90	1 0	10	3 0	N	60	< 050	< 080	40	60	140	2 0
TETRACHLOROBIPHENYLS	190	9 0	1 0	20	60	9 0	N	150	< 10	< 50	1 0	100	250	7 0
PENTACHLOROBIPHENYLS	250	8 0	10	30	100	2 0	N	90	< 10	< 40	40	70	230	4 0
HEXACHLOROBIPHENYLS	440	6 0	10	20	130	80	N	60	< 10	< 40	< 50	30	160	8 0
HEPTACHLOROBIPHENYLS	100	< 2 0	10	< 3 0	60	< 30	N	30	< 080	< 30	< 40	10	120	1 0
OCTACHLOROBIPHENYLS	110	< 2 0	2 0	< 2 0	20	< 20	N	10	060	20	< 20	4 0	70	90
NONACHLOROBIPHENYLS	< 20	< 1 0	1 0	< 80	< 2 0	< 10	N	3 0	< 020	< 070	040	70	2 0	< 50
DICHLOROBENZENE	20	2 0	< 30	< 20	20	060	90	70	080	< 060	< 050	40	60	060
TRICHLOROBUTADIENE	90	20	10	4 0	4 0	1 0	40	270	2 0	5 0	7 0	70	3900	4 0
TETRACHLOROBUTADIENE	270	40	20	10	40	2 0	140	460	10	20	20	120	2800	10
PENTACHLOROBUTADIENE	90	8 0	4 0	7 0	6 0	90	50	140	4 0	3 0	5 0	50	1200	2 0
HEXACHLOROBUTADIENE	90	2 0	6 0	2 0	2 0	90	30	140	1 0	2 0	4 0	60	1100	2 0
% DRY WT	35	45	59	56	41	62	57	52	78	74	76	42	42	56
SAMPLE WT . GRAMS	100	100	99 6	101	101	100	99 6	102	101	99 6	101	98 7	104	99 3

JRB Associates

Table A-5

CONCENTRATIONS OF TARGET ORGANIC COMPOUNDS IN SEDIMENTS FROM OTHER SITES, IN ng/g DRY WEIGHT (PPB)

From Malins et al., 1980, Appendix Table D-5

SAMPLE NUMBER	P MADISON		BUDD INLET			CASE INLET		SINCLAIR INLET			
STATION NUMBER	70	57	35	33	39	36	40	80	96	77	77
1 PROPYLBENZENE	8104	8107	12130	12131	12132	12062	12063	8004	8005	8006	8007
N PROPLYLBENZENE	20	10	70	70	30	10	20	30	30	20	70
INDAN	30	20	50	50	< 40	20	10	40	30	30	40
NAPHTHALENE	10	30	10	40	40	40	40	50	40	50	10
BENZOTHIOPHENE	30	80	30	50	80	20	30	40	50	80	340
2-METHYLNAPHTHALENE	60	< 20	30	10	40	50	20	20	20	40	70
1-METHYLNAPHTHALENE	20	70	10	20	20	20	10	30	40	70	140
BIPHENYL	10	30	60	60	90	10	10	10	20	30	170
2,6-DIMETHYLNAPHTHALENE	40	20	50	60	80	40	< 10	10	10	20	90
ACENAPHTHALENE	10	30	10	90	10	20	10	20	30	50	280
ACENAPHTHENE	< 10	< 10	< 20	< 20	< 30	< 40	< 10	< 20	< 30	< 20	30
FLUORENE	30	< 10	10	10	90	50	20	60	20	20	80
DIBENZOTHIOPHENE	10	40	70	90	50	10	< 10	40	20	30	90
PHENANTHRENE	< 10	30	20	10	10	20	< 30	20	50	10	280
ANTHRACENE	60	20	70	40	90	50	40	70	260	170	1400
FLUORANTHENE	10	30	20	10	20	80	30	20	80	60	780
PYRENE	80	30	160	80	130	100	70	160	460	280	2300
BENZ(A)ANTHRACENE	110	30	170	100	180	90	80	190	460	350	3100
CHRYSENE	70	20	110	50	80	40	30	140	370	270	2100
BENZOFLUORANTHENES	50	20	90	30	50	40	30	120	290	220	1500
BENZO(E)PYRENE	80	40	110	70	120	60	70	290	420	310	1800
BENZO(A)PYRENE	40	10	50	30	60	50	40	120	240	170	930
PERYLENE	30	90	30	10	40	30	70	70	170	140	830
INDENO(1,2,3-CD)PYRENE	40	10	120	30	90	40	40	70	110	90	510
2,3,5 TRIMETHYLNAPHTHALEN	30	10	20	10	40	30	20	90	170	130	670
HEXACHLOROBENZENE	20	40	10	10	90	20	20	30	50	40	320
LINDANE	10	030	10	10	010	040	010	20	40	20	20
HEPTACHLOR	< 060	< 010	< 020	< 010	< 030	< 030	< 010	< 040	< 060	< 030	< 040
ALDRIN	< 010	< 010	< 10	< 10	< 050	< 030	< 010	< 030	< 050	< 020	< 030
O,P' - DDE	< 010	< 010	< 020	< 010	< 040	< 030	< 010	< 040	< 050	< 020	< 030
A-CHLORDANE	30	< 040	< 10	< 10	< 070	< 10	< 050	30	40	20	70
TRANS-NONACHLOR	20	< 020	< 30	< 20	< 20	< 10	< 020	60	80	40	30
P,P' - DDE	20	< 020	< 30	< 20	< 10	< 10	< 020	60	90	40	10
O,P' - DDD	20	< 020	20	70	< 040	< 10	< 030	50	20	60	30
M,P' - DDD	080	< 040	< 30	< 20	< 10	< 10	< 020	80	10	60	30
P,P' - DDD/O,P' - DDT	10	< 060	20	< 20	< 10	< 30	< 030	< 10	< 20	< 60	< 30
P,P' - DDT	30	10	10	60	< 60	30	< 030	80	90	40	10
DICHLOROBIPHENYLS	10	60	10	10	< 080	< 20	< 020	20	30	90	40
TRICHLOROBIPHENYLS	20	10	30	30	20	20	020	60	20	010	30
TETRACHLOROBIPHENYLS	40	40	60	40	50	50	10	30	30	20	10
PENTACHLOROBIPHENYLS	20	10	40	20	30	90	040	10	10	80	30
HEXACHLOROBIPHENYLS	< 20	10	80	60	70	11	20	30	40	20	70
HEPTACHLOROBIPHENYLS	20	20	50	30	60	90	10	50	70	20	60
OCTACHLOROBIPHENYLS	20	< 20	60	30	< 30	< 30	050	40	70	20	70
NONACHLOROBIPHENYLS	40	< 10	40	30	< 20	< 10	< 040	40	20	30	20
DICHLOROBENZENE	080	< 040	< 20	< 10	< 10	< 10	020	20	30	40	20
TRICHLOROBUTADIENE	070	< 10	< 10	< 10	< 40	< 10	< 060	20	< 20	< 10	< 30
TETRACHLOROBUTADIENE	30	50	20	40	30	40	< 030	40	10	20	10
PENTACHLOROBUTADIENE	90	20	20	40	20	60	< 040	10	40	50	30
HEXACHLOROBUTADIENE	40	050	20	70	30	90	< 040	20	80	10	50
% DRY WT	30	20	10	20	050	20	030	30	10	10	60
SAMPLE WT . GRAMS	55	73	28	37	27	25	71	32	33	38	50
	101	99 1	99 4	101	100	100	100	102	99 2	103	101

APPENDIX B

CONCENTRATION OF TRACE METALS AND SYNTHETIC ORGANICS IN THE SEDIMENTS OF ELLIOTT BAY AND IN THE WEST POINT AREA

Concentration of trace metals in µg/g dry weight; organics in ng/g dry weight. Data from Metro/TPPS report (Pavlou, et al., 1983).

AREA B: ELLIOTT BAY/DUWAMISH WATERWAY

	0149		A062	B062	C602	S0036	S0037	S0039	S0063	S0064	Mean ± S.D.
ANTIMONY	5.9	1.8	1.2	0.027	1.5	4.4	1.3	0.7	3.9	4.3	2.5 ± 2.0
ARSENIC	31	28	3.7	4.3	11	23	16	14	7.1	23	16 ± 9.8
BERYLLIUM	0.61	0.58	1.4	0.94	1.3	0.47	0.5	054	0.2	0.46	0.70 ± 0.34
CADMIUM	0.92	0.6	2.3	2.6	2.8	0.53	0.37	1.6	0.28	1.1	1.3 ± 0.15
CHROMIUM	36	48	4.2	50	50	52	64	56	27	53	44 ± 17
COPPER	100	100	460	120	180	150	56	94	90	69	142 ± 118
LEAD	200	223	240	240	340	310	77	150	190	120	209 ± 81
MANGANESE	390	320	340	270	340	360	390	360	160	240	317 ± 73
MERCURY	0.48	0.004	0.088	0.02	0.032	0.44	0.13	0.38	0.4	1.2	0.32 ± 0.36
NICKEL	21	24	40	38	42	32	49	35	4.9	24	31 ± 13
SELENIUM	0.6	0.14	0.095	0.018	0.33	0.24	0.5	0.42	0.2	0.51	0.31 ± 0.20
SILVER	0.79	2.4	0.15	0.9	1.3	2.2	2.4	0.29	0.16	1.8	1.2 ± 0.91
TAHLLIUM	0.1	0.01	0.028	0.009	0.009	0.1	0.1	0.1	0.1	0.1	0.066 ± 0.045
ZINC	220	1420	240	270	350	210	120	190	84	160	326 ± 391

AREA C: ELLIOTT BAY

	A061	B061	C061	S0090	S0065	S0064	MEAN ± S.D.
ANTIMONY	0.41	0.35	0.22	1.3	3.5	0.7	1.1 ± 1.3
ARSENIC	8.4	13	8.8	4.2	20	9.9	11 ± 5.3
BERYLLIUM	0.36	0.41	0.31	0.18	0.46	0.35	0.35 ± 0.10
CADMIUM	0.49	0.37	2.2	0.75	0.62	0.4	0.81 ± 0.70
CHROMIUM	59	63	45	28	42	45	47 ± 13
COPPER	64	64	36	11	64	46	48 ± 21
LEAD	130	130	55	84	100	63	94 ± 32
MANGANESE	260	290	240	290	300	210	282 ± 26
MERCURY	0.024	0.072	0.022	0.12	0.92	0.18	0.22 ± 0.35
NICKEL	45	47	41	25	31	30	37 ± 9.0
SELENIUM	1.1	0.39	0.35	0.20	0.7	0.2	0.49 ± 0.35
SILVER	1.9	1.9	1.6	2.1	1.9	1.2	1.8 ± 0.32
THALLIUM	0.007	0.01	0.006	0.10	0.1	0.1	0.054 ± 0.051
ZINC	1020	1080	757	210	120	120	551 ± 454

AREA D: N.E. ELLIOTT BAY/DENNY WAY CSO

	401406		401512		401603		401606		401612		401706		401810		A060	B060	C060	S0031	S0032	Mean ± S.D.
ANTIMONY	3.2	1.5	2.3	0.87	2.6	3.3	1.3	0.46	3.7	1.0	3.2	0.6	1.0	0.94	0.87	1.3	0.03	0.9	0.45	1.5 ± 1.1
ARSENIC	8.8	15	12	13	15	16	12	9.1	16	14	15	12	12	11	0.53	12	44	11	9.3	14 ± 8.2
BERYLLIUM	0.33	0.35	0.30	0.37	0.21	0.26	0.41	0.16	0.3	0.11	0.4	0.2	0.37	0.18	0.79	1.1	0.89	0.36	0.33	0.39 ± 0.26
CADMIUM	0.99	2.1	0.32	0.39	0.46	2.2	0.15	0.34	0.7	0.36	0.86	0.63	0.47	0.33	2.8	1.5	1.5	0.71	0.86	0.93 ± 0.75
CHROMIUM	60	61	48	57	57	63	63	45	60	59	59	53	54	49	39	50	51	58	52	55 ± 6.5
COPPER	130	87	52	55	120	120	57	34	62	54	61	54	82	58	96	140	61	47	49	75 ± 32
LEAD	89	210	54	96	430	670	88	49	90	98	95	100	82	120	220	120	110	100	120	155 ± 151
MANGANESE	300	310	300	280	200	270	400	210	330	300	420	310	580	300	220	280	290	250	200	300 ± 90
MERCURY	0.98	1.0	1.6	0.34	1.3	1.6	0.77	0.22	0.72	3.4	0.62	0.72	0.65	0.61	0.71	0.012	0.007	0.26	0.06	0.82 ± 0.78
NICKEL	44	44	40	51	41	49	56	50	48	50	49	58	39	45	54	58	63	42	38	48 ± 7.1
SELENIUM	0.48	0.20	0.56	0.20	0.2	0.2	0.4	0.2	0.78	0.2	0.48	0.2	0.2	0.2	0.07	0.65	0.02	0.2	0.2	0.3 ± 0.2
SILVER	4.6	1.1	3.4	2.1	0.9	4.1	5.4	1.3	3.9	1.5	5.2	2.2	2.1	2.4	0.72	1.2	0.89	6.0	1.9	2.7 ± 1.7
THALLIUM	0.10	0.10	0.1	0.10	0.1	0.1	0.1	0.1	0.1	0.1	0.10	0.1	0.1	0.1	0.007	0.015	0.01	0.1	0.1	0.086 ± 0.033
ZINC	140	170	100	110	240	300	150	86	120	110	136	110	120	120	210	140	180	100	100	145 ± 57

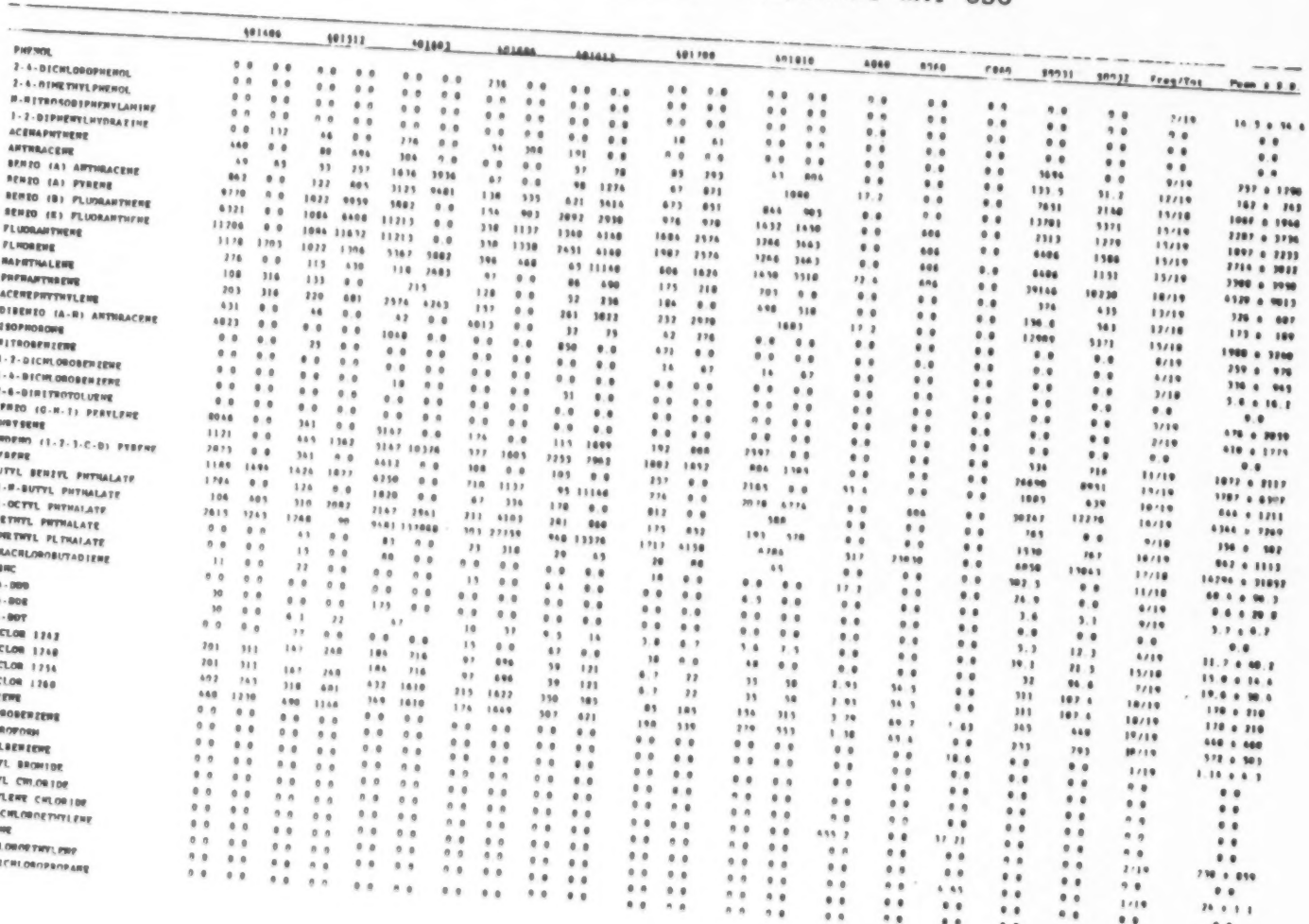
AREA F: WEST POINT

	400210		400310		400330		400430		400510		400530		400621		400712		400810		400830		S0004	S0005	S0010	S0099	S0100	S0101	S0102	S0103	S0104	400730	Mean ± S.D.
ANTIMONY	0.6	0.33	1.3	0.93	0.8	0.3	0.3	0.33	1.3	0.9	0.8	0.33	0.6	0.3	0.6	0.6	0.7	0.33	0.3	0.33	0.33	0.98	0.8	0.3	0.3	1.3	0.9	2.1	3.5	0.33	0.3	0.84 ± 0.69
ARSENIC	5.2	10	6.8	3.8	9.2	6.1	7.2	8.4	6	1.9	3.7	6.5	4.2	15	3.4	6.8	33	3.8	29	6.8	4.7	6.1	2.8	3.8	3.8	6.2	3.6	7.3	7.2	5.3	6.7	6.2 ± 5.2
BERYLLIUM	0.15	0.09	0.2	0.21	0.26	0.12	0.51	0.26	0.12	0.14	0.7	0.26	0.16	0.11	0.23	0.26	0.22	0.21	0.78	0.33	0.21	0.2	0.2	0.12	1.15	0.18	0.13	0.19	0.17	0.16	0.41	0.32 ± 0.26
CADMIUM	0.07	0.15	0.6	0.3	0.35	0.1	0.43	0.1	0.08	0.08	0.06	0.07	0.01	0.07	0.14	0.08	0.1	0.03	0.18	0.16	0.05	0.66	0.11	0.17	0.1	0.75	0.48	1.2	2.6	0.03	0.23	0.30 ± 0.40
CHROMIUM	17	19	37	29	34	45	38	48	8.9	20	13	26	18	24	21	33	24	21	82	62	31	31	34	30	32	28	31	24	26	23	18	29 ± 11
COPPER	20	7.2	27	31	52	15	37	25	13	7.6	17	14	6.9	12	14	16	33	18	28	21	8	11	13	9.5	8.7	11	12	11	15	13	20	17 ± 9.8
LEAD	19	13	31	17	51	22	62	27	13	10	18	28	13	16	62	24	17	13	19	21	18	18	15	29	16	84	43	130	190	23	17	33 ± 30
MANGANESE	360	360	240	190	390	460	320	380	200	160	180	160	420	300	370	320	380	630	650	1000	400	380	280	260	270	290	230	380	210	460	420	400 ± 170
MERCURY	0.15	0.05	0.37	0.27	0.2	0.17	0.58	0.22	0.16	0.05	0.11	0.08	0.05	0.01	0.13	0.11	0.15	0.47	0.05	0.11	0.025	0.025	0.13	0.17	0.12	0.12	0.22	0.2	0.49	0.05	0.27	0.17 ± 0.16
NICKEL	17	25	31	32	36	26	31	36	21	23	18	24	19	23	18	20	8.3	19	47	48	28	29	29	29	29	25	29	30	30	26	27	26 ± 7.5
SELENIUM	0.2	0.2	0.2	0.2	0.2	0.37	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.14	0.22	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.22 ± 0.10
SILVER	1.8	0.83	1.6	0.26	2.8	0.26	4.2	0.65	1	0.03	1	0.21	0.82	0.05	1.3	0.2	1.1	0.30	0.21	0.28	1	0.92	0.24	0.83	0.28	2.1	0.78	0.78	1.5	0.86	2.9	0.80 ± 0.90
THALLIUM	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.025	0.026	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1 ± 0.03
ZINC	44	38	83	67	72	57	120	68	45	29	59	45	28	57	78	56	51	57	84	73	61	65	61	120	93	210	160	310	960	38	81	98 ± 101

AREA EE: CENTRAL ELLIOTT BAY

	0150	401230		401630		401830		S0015	S0062	MEAN ± S.D.
ANTIMONY	0.31	0.5	0.67	0.8	0.53	1	0.67	1.1	0.86	0.72 ± 0.25
ARSENIC	8.8	13	14	12	8	10	11	14	10	11 ± 2.2
BERYLLIUM	0.45	0.36	0.4	0.45	0.07	0.44	0.24	0.83	0.35	0.40 ± 0.20
CADMIUM	0.25	0.25	0.46	0.23	0.05	0.3	0.14	0.38	0.36	0.27 ± 0.12
CHRONIUM	53	54	47	37	11	47	47	59	56	46 ± 15
COPPER	61	62	50	55	13	50	46	49	61	49 ± 15
LEAD	87	55	81	68	30	62	72	53	68	64 ± 17
MANGANESE	290	420	380	380	130	340	330	400	300	330 ± 87
MERCURY	0.004	0.43	0.29	0.63	0.06	0.53	0.34	0.22	0.52	0.34 ± 0.21
NICKEL	32	32	38	27	13	31	43	36	29	31 ± 8.4
SELENIUM	0.49	0.2	0.3	0.33	0.2	0.2	0.34	0.36	1	0.38 ± 0.25
SILVER	2.9	3.9	0.24	3.6	0.05	2.3	0.74	0.41	0.75	1.7 ± 1.5
THALLIUM	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.53	0.1	0.14 ± 0.15
ZINC	1180	100	100	120	50	110	100	130	100	221 ± 360

AREA D: NORTHEAST ELLIOTT BAY/DENNY WAY CSO



AREA F: WEST POINT

	480120		480310		480330		480430		480510		480530		480621		480712		480730		480810		480836		80004	80005	80010	80099	80100	80101	80102	80103	80104	Freq/Tot	Mean ± S D
PHENOL	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	29 0 0		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	66	87	0 0	70	0 0	0 0	4/33	0 4 ± 24
2-4-DICHLOROPHENOL	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
2-4-DIMETHYLPHENOL	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4-NITROSODIPHENYLAMINE	16	0 0	196	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
1-2-DIPHENYLHYDRAZINE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
ACENAPHTHENE	12	35	107	1334	2 7	117	29	142	4 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
ANTHRACENE	126	517	1273	9964	16	136	233	360	0 0	0 0	9 6	0 0	0 0	0 0	4 5	64	12	0 0	37	104	488	0 0	0 0	107	117	57	45	20	44	17	432	5/33	40 ± 32
BENZO (A) ANTHRACENE	344	1151	4402	14947	81	341	748	1715	0 0	0 0	106	124	61	0 0	34	203	78	189	22	20	4 0	21	0 0	2 7	84	396	225	284	1060	1071	12042	23/33	0 0
BENZO (A) PYRENE	349	816	6824	22198	120	490	1002	3662	0 0	0 0	273	0 0	194	0 0	46	313	265	1757	95	298	162	205	0 0	61	408	1726	1321	896	4436	2242	28602	28/33	107 ± 254
FLUORANTHENE (B) FLUORANTHENE	737	855	8805	38612	110	559	1233	4317	65	0 0	177	862	323	0 0	193	339	1622	1852	93	189	471	572	0 0	847	548	5430	2510	1581	9933	6426	30105	28/33	828 ± 272
BENZO (K) FLUORANTHENE	536	855	8805	90767	110	736	1618	4117	83	0 0	160	273	310	0 0	193	663	1757	2269	136	630	363	631	0 0	680	704	6111	2114	2108	9799	5221	28796	28/33	3579 ± 3256
FLUORANTHENE	689	1203	8269	71352	336	858	1572	2744	76	0 0	620	614	401	0 0	193	663	1757	2269	136	1402	612	869	0 0	860	843	6111	2114	2108	9799	5221	28796	28/33	3208 ± 8698
FLUORENE	21	83	843	4804	6 0	156	79	324	0 0	0 0	34	106	44	0 0	33	38	31	48	45	85	10	293	0 0	860	843	6111	2114	2108	9799	5221	28796	28/33	3731 ± 8432
INDENO(1,2,3-C,D)PYRENE	0 0	0 0	328	2669	129	0 0	139	308	0 0	0 0	33	0 0	0 0	0 0	27	62	65	0 0	65	0 0	0 0	0 0	0 0	207	117	239	84	91	255	247	2894	28/33	5625 ± 16735
NAPHTHALENE	32	31	643	3278	12	31	50	267	4 1	0 0	107	259	298	0 0	285	343	391	391	61	164	84	135	0 0	0 0	0 0	102	36	33	603	32	2894	27/33	4268 ± 12944
PHENANTHRENE	383	601	3150	33636	61	477	1032	1166	23	0 0	23	0 0	35	0 0	60	67	48	51	33	91	460	0 0	73	333	592	3030	2321	2107	5235	1265	23560	29/33	319 ± 913
PYRENE	362	523	5749	9093	61	150	343	1012	0 0	0 0	191	0 0	142	0 0	138	313	2432	0 0	305	6 8	0 0	0 0	0 0	2 7	84	396	225	284	1060	1071	12042	28/33	394 ± 943
BUTYL BENZYL PHTHALATE	23	0 0	0 0	0 0	11	0 0	20	24	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	11	0 0	37	20	11	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
DI-N-BUTYL PHTHALATE	43	96	262	0 0	25	112	103	780	16	623	28	164	187	1423	45	194	198	1672	101	2135	33	167	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
DI-OCTYL PHTHALATE	2329	3571	1423	0 0	173	0 0	51	431	357	623	0 0	0 0	203	434	234	1165	484	3600	258	390	181	255	163	12533	1479	3030	806	0 0	0 0	283	2749	27/33	1110 ± 2324
DIETHYL PHTHALATE	17	0 0	9 3	0 0	9 3	0 0	17	0 0	0 0	0 0	47	0 0	23	0 0	27	56	8 1	10 0	10	47	8 4	12	0 0	27	0 0	35	0 0	0 0	13	9 4	58	19/33	35 ± 22
DIMETHYL PHTHALATE	23	0 0	0 0	0 0	20	0 0	17	31	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	6 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	7 3 ± 22
HEXACHLOROBUTADIENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 1 ± 2 5
A-BHC	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	11	0 0	3 9	0 0	3 0	0 0	6 8	0 0	5 6	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
A-A-DDC	0 0	0 0	2 0	12	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
A-A-DDE	0 0	0 0	1 3	3 0	27	4 0	62	3 4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	6 6	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
A-A-DDT	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 5	67	0 0	0 0	1 1	1 2	3 6	2 1	10	2 6	2 2	2 8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
AROCLOR 1242	12	19	26	128	4 6	16	15	45	6 8	9 1	10	27	33	0 0	8 1	19	27	65	34	37	22	67	2 8	2 7	45	1 6	2 0	0 0	2 0	1 3	6 5	5/33	83 ± 2 8
AROCLOR 1248	12	19	26	128	4 6	16	15	45	6 8	9 1	10	27	33	0 0	8 1	19	27	65	34	37	22	67	2 8	2 7	45	1 6	2 0	0 0	2 0	1 3	6 5	21/33	1 8 ± 2 5
AROCLOR 1254	18	21	52	448	5 3	41	32	57	5 2	8 2	25	63	44	0 0	20	21	49	57	29	38	52	112	3 8	2 7	130	4 3	10 6	8 3	15	9 6	65	30/33	61 ± 1 8
AROCLOR 1260	3 8	21	52	365	5 3	52	31	48	3 9	9 8	30	33	3 3	0 0	21	36	45	56	34	81	36	92	3 9	2 6	78	2 3	4 0	2 6	6 7	4 0	26	30/33	20 ± 30
BENZENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
CHLOROBENZENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
CHLOROFORM	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
ETHYLBENZENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
METHYL BROMIDE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
METHYL CHLORIDE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
METHYLENE CHLORIDE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
TETRACHLOROETHYLENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
TOLUENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
TRICHLOROETHYLENE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
1-2-DICHLOROPROPANE	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

APPENDIX C

ESTIMATION OF ORGANIC CARBON CONTENT

Table C-1

PERCENTAGE OF SEDIMENT ORGANIC CARBON AT METRO/TPPS STATIONS AS ESTIMATED FROM THE PERCENTAGE OF FINES
(The regression used is shown in Figure 8)

Station Number	% Fines	% Organic Carbon
Area B		
0149	68.4	2.4
A062	74.2	2.6
B062	61.1	2.2
C062	89.1	3.0
S0063	16.4	0.8
S0064	69.9	2.4
Area C		
A061	57.9	2.1
B061	52.4	1.9
C061	52.0	1.9
S0090	84.5	2.9
S0065	81.4	2.8
Area D		
401406	75.6	2.6
401512	81.8	2.8
401603	39.9	1.5
401606	91	3.1
401612	82	2.8
401810	68.7	2.4
A060	40.1	1.5
B060	89.2	3.0
C060	91.5	3.1

Station Number	% Fines	% Organic Carbon
Area F		
400310	12.3	0.69
400330	18.6	0.88
400430	26.8	1.12
400510	7.8	0.55
400530	13.1	0.71
400621	4.8	0.46
400712	11.7	0.67
400730	7.7	0.55
400810	7.5	0.54
400830	29.8	1.21
S0004	5.7	0.49
S0005	8.2	0.57
S0010	7.4	0.54
S0099	7.4	0.54
S1100	6.7	0.52
S0101	7.4	0.54
S0102	9.5	0.61
S0103	8.2	0.57
S0104	11.9	0.68
Area EE		
0150	71.4	2.46
401230	7.5	0.55
401630	68.7	2.38
401830	92.4	3.09
S0015	55.1	1.97
S0062	83.4	2.82